RURAL ECONOMY

Economic Evaluation of Manure Management and Farm Gate Applications

A Literature Review of Environmental and Economic Aspects of Manure Management in Alberta's Livestock Sectors

James R. Unterschultz and Scott R. Jeffrey

Project Report # 01-03

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This project was funded by the Wild Rose Agricultural Producers. The Wild Rose Agricultural Producers received assistance from the PFRA National Soil and Water Conservation Program (NSWCP). The following graduate students and research assistants at the University of Alberta have participated in researching and writing the report.

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All final conclusions and errors remain the responsibility of the supervising researcher, J. Unterschultz. Scott Jeffrey, Associate Professor, University of Alberta was the co-researcher on this project.

Abstract

Livestock operations in Alberta have a significant impact on the economy. Manure is a by-product of livestock production. The review of the science on manure examined the environmental impacts of manure. These impacts include water pollution, air pollution, climatic change, and soil degradation. There are several technologies that may be used to manage manure on-farm and off-farm. These include nutrient recycling through soil application and composting. Composting reduces the volume of manure, but increases the nitrogen losses from the manure

This review, using a very simplistic approach, estimated that more than 6.3 million tonnes of manure were generated in Alberta in 1996. Other studies have estimated significantly higher annual manure production. On a province-wide basis, there is adequate cropland area to make use of all the nutrients available in the manure produced. However, manure production tends to be concentrated on smaller land areas. Benefits of manure are constrained by both hauling costs and the costs of managing the manure itself. The on-farm economic costs or benefits are not well documented. Four general approaches have been used to analyze the on-farm economics of manure management.

- Opportunity Cost: Value the nutrient content of manure using commercial fertilizer values and consider the manure or manure product as a commercial fertilizer substitute or supplement.
- Crop Benefit: Value the direct crop benefit through a comparison of production in soil with manure applied versus a control with no manure applied.
- Cost of Business: View the manure exclusively as a by-product of livestock production and evaluate methods for minimizing the cost of disposal.
- Business Enterprise: View manure production as a value-added business and evaluate as a separate business enterprise using an appropriate approach.

Any detailed economic analysis should incorporate the dynamic nature of manure production, and the management of manure through recycling through soil. Only one study was identified that was based on Alberta conditions and utilized a systems approach. At best, only one of the published studies explicitly incorporated the dynamic interactions of the livestock operation with a cropping enterprise, to analyze the on-farm economics of manure. This may be, in part, related to the complexities of modeling the key components in the system, while including the dynamic time-related interactions between soil, manure, and the environment. Those studies that attempted a systems approach or, at the very least, a more complete investment analysis, generally showed manure to be a net cost to the farm business. Little farm gate economic research applicable to Alberta on cost and benefits of manure systems for commercial farms for feedlots, dairy, pork or poultry was found. Future research could focus on a) economic case studies of selected farms to value manure management systems and b) working towards a systems analysis of manure management for Alberta livestock farms.

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Introduction

Rationale for the Study

Agriculture is a significant part of Alberta's economy. The livestock sector in Alberta is the largest farm cash earner (AAFRD 2000-e). Beef production contributes more that one half of these earnings (AAFRD, 2000-e). Globally, as well as in Alberta, intensive livestock production is concentrated in fewer geographical areas (Janzen et al. 1999). Livestock and animal manure are joint products. Production of the livestock produces manure as a by-product. Manure management is therefore a key component in any livestock production system.

The livestock population in Alberta is not evenly distributed. Southern Alberta has higher livestock population concentrations, particularly for beef cattle. This concentration in Southern Alberta is in part due to its proximity to the U.S. market and processing facilities, a favorable climate, abundance of feed supplies, and availability of water (AAFRD - Irrigation Branch, 1995). Lethbridge county alone has approximately 7% of Alberta's cattle and calf population (Statistics Canada, 1996). Conversely cattle densities are lower in Northern Alberta. For example, the county of Grand Prairie has only 1.4% of Alberta's cattle and calf population (Statistics Canada, 1996).

Management of manure has become an issue in several regions of Alberta. These tend to be the regions of higher livestock densities. In Southern Alberta, for example, contamination of surface and groundwater with nitrogen and other contaminants is currently seen to be a growing problem (Power and Schepers, 1989; Western Producer, 2000). Manure's bulkiness hampers its transportation from manure-abundant to manure-deficient areas. As a result, manure management in high-density livestock areas is a very important priority.

Within the list of 1992 priorities for the Canadian Agricultural Research Council, emphasis was placed on: 1) productivity, 2) resource management, 3) waste management, 4) agriculture/environment interaction, and 5) food quality. Manure management directly relates to the waste management and agriculture/environment interaction priorities and is indirectly related to the others (Paul and Agassiz, 1999). McRae et al. (2000), in their report for AAFC, assess the overall agriculture and ecosystem sustainability for Canada. Sustainable agriculture is a key issue to agriculture, society, and the environment. The importance of these issues for Alberta agriculture renders an understanding of the economic and non-economic aspects of manure management crucial, given the presence of areas with high livestock densities (e.g. Lethbridge region).

Study Objective

Many studies address manure management focus on Best Management Practices (BMPs) as the corner stone in achieving the two principal objectives of applying animal manure. These objectives are: 1) to ensure maximum utilization of the manure nutrients by crops and 2) to minimize water pollution hazard (Ohio State University, 2000). However, BMPs vary widely according to agronomic conditions (AAFC, 1998). Therefore, a Best Management Program in one place may not be appropriate for adoption in a different location. As animal production is one of Alberta's major industries, especially in the southern Alberta, managing manure for sustainable agriculture is very important. One difficulty is that information required to evaluate the benefits and costs of manure management is fragmented.

The overall objective of this paper is to enhance the information base currently available relating to the economics of managing animal manure by reviewing relevant literature. Specific objectives are:

- Identify information gaps in the area of economics of manure management for the Alberta livestock industry,
- Provide information that allows managers to initially evaluate different manure management methods in Alberta,
- Assist manure generators and users in decision-making,
- Identify areas of future research related to the economics of livestock waste management.

Outline for the Paper

The review has seven key sections. The first two sections provide a relatively non-technical review of the science and the environmental issues associated with livestock production and manure management in Alberta. These sections assist the reader in understanding the issues associated with intensive livestock production and the impact of manure on the environment and society.

The following two sections identify the extent of manure production in Alberta, and review the technologies used for managing manure in Alberta. These sections provide background concerning the size of the manure management problem, the current technologies used to manage manure in different intensive livestock operations and the technologies that appear to be most commonly used in Alberta. A review of the on-farm economic analysis, as reported in the literature, is then provided. Results from several studies provide some level of economic analysis related to the on-farm cost and benefits associated with manure management. The final sections present conclusions and suggestions for further economic research on farm costs and benefits, and on policy areas as these relate to sustainable intensive livestock production.

The Science of Manure

Animal waste management is of great importance in Alberta, due to high animal densities, and high nutrient leaching potential in specific regions of Alberta. Because of its importance, the Alberta government is currently working towards a way of regulating the livestock industry, to ensure that the industry continues to evolve and grow in an environmentally sustainable manner that protects human health, and the rights of individuals (Barnes, 1998). Animal manure contains nitrogen (N), phosphorus (P) and potassium (K), as well as sulfur, calcium, magnesium, copper, boron, iron, molybdenum, zinc, selenium, chromium, cobalt, iodine and chlorine (Palmquist et al. 1997). It also supplies the soil with organic matter. Governments have placed emphasis on the use of land as a recycling system, where the nutrients and organic matter applied to farmland through manure are used to balance those nutrients removed through crops production (Barnes, 1998).

Nitrogen in the soil exists in either soluble forms, such as NH_4^+ (ammonia) and NO_3^- (ammonium nitrate) (Westerman, 1988), or insoluble forms such as N associated with organic matter and NH_4^+ associated with clays (Hopkins et al. 1991). NH_4^+ and NO_3^- are soluble to plants but N associated with organic matter is not. To be available, N needs to be changed into NH_4^+, which is an inorganic form. This conversion is referred to as mineralization (Hopkins et al. 1991). NH_4^+ can be used directly by plants or changed into NO_3^- through a process known as nitrification. NO_3^- is very soluble in the soil. However, unlike NH_4^+, it is not attracted by the soil's negatively charged colloids, thereby rendering NO_3^- easily leachable with excess water (Young and Aldag, 1982).

This is the route (i.e. NO_3^-) that is causing concern over nitrogen pollution from livestock operations (Hopkins et al. 1991). High concentrations of NO_3^- in drinking water have negative health effects. Areas of intensive irrigation, most of which are concentrated in southern Alberta, are particularly susceptible to nitrate contamination of groundwater due to the relatively shallow depth of the water table and the periodic leaching necessary to control salt accumulation (Power and Schepers, 1989). In poorly aerated soils NO_3^- is converted to N_2 (nitrogen gas) and volatized into the atmosphere by anaerobic bacteria through a process known as denitrification. Risks of loss through run-off, leaching and denitrification increase with particular management regimes.

Plant nutrients, which are contained in both manure and chemical fertilizers, are essential to crop production. When applied in proper quantities and at appropriate times, the nutrients from manure aid in achieving optimum crop yields (Nova Scotia Department of Agriculture and Marketing 1997, 2000). However, if improperly used, the nutrients and bacteria in manure can be a potential environmental and health hazard for groundwater and streams (Koroluk et al. 2000).

Water Pollution

Some researchers claim that water pollution represents the greatest environmental hazard caused by manure (Laura and Zering, 1997). Groundwater and surface water issues predominantly involve the potential risk for large-scale nitrogen leaching and run-off from feedlots, manure storage structures, and from fields on which manure has been spread. Run-off from these sources poses the greatest threat of nitrogen contamination in surface water (Paterson and Lindwall, 1992). Run-off is promoted by soil compaction resulting from animal confinement. Run-off carrying manure adds nutrients, organic matter and microorganisms to surface water, promoting the growth of unwanted aquatic plants and algae (AAFRD, 1999-a). The death and decomposition of algae can generate offensive taste and odour problems in drinking water supplies and increase water treatment cost. Algae can also release toxins when they decay and die (AAFRD, 2000-e). High levels of ammonia in run-off from manure can also kill fish (AAFRD, 1999-a).

Concentrations of NO_3^- over 10 mg L^{-1} are known to cause a health condition called methaemoglobinaemia, also known as Blue Baby Syndrome, where the blood haemoglobin is incapacitated in its ability to carry oxygen (Hopkins et al. 1991). This syndrome can be fatal to infants (North Carolina Cooperative Extension Services, 1995). Areas with coarse or sandy soils are considered to have a greater risk of NO_3 leaching into ground water (AAFRD, 1999-b). Canadian drinking water guideline for human consumption is set at 10 mg per litre or 10 ppm.

In addition to nitrogen, phosphorus is another nutrient in manure that may pollute water (Bolinder et al. 2000). Manure applications to soil may be contributing to excessively high soil phosphorus levels. High levels of nitrogen and phosphorus in slow moving or stagnant surface waters can cause a phenomenon called eutrophication (North Carolina Cooperative Extension Services, 1995). Eutrophication is defined as the enriching of natural waters with plant nutrients. The nutrients are usually nitrogen or phosphorus, thus enabling the growth of aquatic plants. Eventually, these plants die due to seasonal effects or overcrowding. The decaying organic matter exerts an oxygen demand on the water and may exhaust the water's natural oxygen supply. This in return can cause mass death of fish and other aquatic species. Phosphorus concerns are a dynamic issue since past phosphorus levels impact on current phosphorus levels.

Phosphorus run-off, especially through soil erosion, is a concern in other countries. Johnsen (1993) evaluated economic measures to control the run-off of phosphorus from non-point agricultural sources in Norway. He recommended taxation on phosphorus as one way to control the problem. McCann and Easter (1999) indicate that phosphorus run-off from non-point agricultural sources is a concern in the United States Minnesota River basin. Their study evaluated attitudes to policies designed to reduce phosphorus pollution from soil run-off and manure management. This problem with phosphorus run-off from soils in the United States is mentioned also by Schnitkey and Miranda (1993).

Harmful microorganisms found in manure may also contaminate groundwater. Because most manure heaps are not covered, rainfall washes soluble nutrients and harmful microorganisms into groundwater and surface water (Agriculture and Agri-Food Canada, 1998-b). Manure contains fecal coliform bacteria, and may contain other disease-causing microorganisms such as Cryptosporidium, Giardia (AAFRD, 1999-c) and Escherichia coli (Miller et al. 1999). These microorganisms are a threat to public health, and can reduce weight gains and productivity in livestock, if the manure carried in run-off reaches drinking water supplies.

Some of the nutrients washed out from feedlots (and fields receiving manure) overload in the soil. This is a potential risk to groundwater and surface water (Laura and Zering, 1997). In fact, researchers claim that manure overloading in soil poses the greatest threat to groundwater (Paterson and Lindwall, 1992). The results from Janzen et al. (1999) indicate that overloading may be occurring in most regions in Alberta on selected fields.

Air Pollution

While water pollution may represent the greatest environmental hazard caused by manure, most protest or concern has often been against air quality (Hopkins et al. 1991; Serecon 1998). Air quality concerns surrounding manure include ammonia volatility, methane emissions, dust, and, most importantly, odour. Up to 90% of the nitrogen in manure can be lost in the form of nitrogen gas or ammonia, which produces a repulsive, pungent smell of rotten eggs when improperly managed (McCalla et al. 1970). When left lying on the surface in feedlots, a significant amount of nitrogen can be lost. In many soils, the P and K status is adequate, but N is in short supply (Grundey, 1980). Therefore, loss of nitrogen from manure implies loss of its fertilizer value to the farmer as well as contributing to lower air quality. The issue of what to do with the odour and nutrients from manure is one of the most contentious policy issues confronting agriculture today (Fleming et al. 1998).

Global Warming

It is hypothesized that manure production adds to global warming through its contribution to green house gas concentrations. These atmospheric trace gases (referred to as greenhouse gases) include Carbon Dioxide (CO_2)**,** Methane (CH_4) and Nitrous Oxide (N_2O), all of which are released from manure. These gases absorb and radiate the outgoing flow of infrared radiation, effectively storing some of the heat in the atmosphere (George Mason University, 1997; McRae et al. 2000). The outcome of this process is a net warming of the atmosphere. The process is called the greenhouse effect.

Nitrous oxide (N_2O) and nitric oxide (NO) are gases that are produced not only during the burning of fossil fuels, but also as a result of microbial activity in soil and in decomposing organic wastes. Both gases are secondary products formed during the processes of nitrification, where ammonium is oxidized to nitrate, and denitrification, where nitrate is lost to the atmosphere as Nitrogen (N_2) gas (Paul and Agassiz, 1999). Decomposition of animal manure during storage and after application of manure to fields produces significant quantities of N_2O and NO. Both N_2O and NO are considered environmental contaminants. Field experiments have shown that manure application to soil increases N_2O emissions (Stevens and Cornforth, 1974; Egginton and Smith, 1986; Cabrera et al. 1994). N_2O is 300 times more powerful than CO_2 as a greenhouse gas and also contributes to ozone destruction in the upper atmosphere (Alberta Cattle Commission, 2000). Larney and Carcamo (1999) point out that composting manure also contributes to greenhouse gas emissions.

Although livestock manure produces CO_2, another atmospheric trace gas, the oceans play a major role in balancing the atmospheric carbon dioxide levels. The global carbon dioxide budget is complex and involves transfer of CO_2 between the atmosphere, the oceans, and the biosphere (George Mason University, 1997; Desjardins and Riznek, 2000). Through the process of photosynthesis, the land removes about 100 petagrams (10^{15} g) of carbon in the form of CO_2 per year. About the same quantity of carbon in the form of CO_2 is added to the atmosphere each year by vegetation and soil respiration and decay (George Mason University, 1997). The world's oceans release about 100 Pg C in the form of CO_2 into the atmosphere per year and in turn absorb about 104 Pg C each year. By summing all of the fluxes of CO_2 into and out of the atmosphere, researchers can find that about 3 petagrams of carbon in the form of CO_2 is building up in the atmosphere each year.

Methane is another greenhouse gas that is released during manure storage. It is also emitted from any decaying organic matter. Livestock manure may account for 6-10% of global methane emissions (Safley et al. 1992). Husted (1994) estimated annual methane emissions from pig slurry and cattle slurry to be 8.9 and 15.5 kg per animal per year, respectively. A herd of 100 cattle can yield as much as 4,000 ft^3 of methane gas (Hansen et al. 1976). Methane is up to twenty five times more harmful than carbon dioxide in its potential effect on global warming (Noble, 1989).

The agricultural livestock industry has been considered a major source of carbon dioxide**,** methane and nitrous oxide. Desjardins and Riznek (2000) calculate that in 1996, agriculture in Canada contributed 86 megatonnes to greenhouse gases when measured in carbon dioxide equivalents[1]. This represents 13% of total greenhouse gas emissions in Canada. Emissions have increased over time. Manure is the largest contributor to greenhouse gases in Canada from agricultural sources. Approximately 20 megatonnes of greenhouse equivalents were emitted by manure in Canada in 1996. Alberta is the largest provincial contributor to agricultural emissions of greenhouse gases in Canada (Desjardins and Riznek, 2000). Alberta contributed over 20 megatonnes of carbon dioxide equivalents in 1996. The next largest contributor, Saskatchewan, contributed approximately 11 megatonnes from agricultural sources. Desjardins and Riznek (2000) indicate that there is a high degree of uncertainty surrounding these estimates. AAFRD (2000-f) reported that, of the carbon dioxide equivalents emitted in Alberta in 1996, 91.5% were from the beef industry, 4.3% were from the dairy industry, and 1.8% were from the hog industry.

The issue of greenhouse gas emissions from agriculture is a growing concern. Alberta is the largest contributor to greenhouse gases from agricultural sources. Manure is the largest source of agricultural emissions. Thus, by implication, the livestock industry in Alberta needs to be highly aware of greenhouse gas issues.

Soil Productivity

Application of manure can also adversely impact on the soil. The proposed Alberta guidelines for intensive livestock regulations recognize the potential adverse impact of "salts" and other "contaminants", such as metals, that are found in certain types of manure (AAFRD 2000-d, Schoenau 2000, Grevers et al. 1999). The next section briefly examines the technical information on reducing the adverse impacts of manure on soils and the environment.

[1] Desjardins and Riznek (2000, p. 135) present a brief discussion on calculating carbon dioxide equivalents from nitrous oxide and methane. Methane is considered 21 times more effective than carbon dioxide in global warming potential. Nitrous oxide is 310 times more effective than carbon dioxide in global warming potential.

Strategies for Minimizing Adverse Impacts of Manure Management on the Environment

Researchers exhibit two general views regarding manure. Manure can be considered a livestock production waste by-product or a valuable source of plant nutrients. If a producer treats manure as a waste by-product, then research and analysis should focus on evaluating waste management techniques that reduce the nutrient content of applied manure, or reduce the adverse environmental impact of manure at least cost to the producer and society. If manure is a valuable resource, then policy-makers should encourage farmers to adopt nutrient management techniques (Fleming et al. 1998; Solberg, 2000; Larney, 2000) that "increase the value" of the manure. The economic research presented in the economics section below suggests that manure, in most cases, is a net cost to the livestock business.

Manure As a Plant Nutrient

The nutrient content of animal manure varies with the ration fed to an animal, type and breed of an animal, the manure management system, storage methods, amount and type of bedding material used in pens, and climate. In general, 3/4th of nitrogen, 4/5th of phosphorus, and 9/10th of potassium ingested by animals are excreted in manure (Younos, 1990). Utilizing these nutrients as plant nutrient makes sense, if application of manure results in reduced use of commercial fertilizers, or if the total nutrient benefit value of animal manure is greater than hauling and other manure management costs. Recycling manure through soil application may also have the lowest cost, and the least adverse environmental impact.

One strategy used by farm managers to optimize the use of farm inputs and manage environmental risks is the "Best Management Plan" (BMP). BMP's involve managing manure, which ensures maximum utilization of manure nutrients by the crops, and minimizing adverse impacts on the environment. Ensuring maximum utilization involves manure application based on the nutrient requirements of plants, nutrients available in soil, and the nutrient content of manure (Nova Scotia Department of Agriculture and Marketing, 2000).

Commercial inorganic fertilizers can be blended to meet the exact multi-nutrient requirements of crops. This type of nutrient flexibility is not available with manure, particularly when managers try to meet all the crop requirements (Olson et al. 1999). When manure application is based on one nutrient, other nutrients will be over or under-applied. In spite of its practical shortcomings relative to modern agricultural chemicals, manure is an excellent organic soil amendment that is available on the farm. It is a source of nutrients that can improve soil tilth and structure.

One approach to evaluating the on-farm benefits or costs of manure is the opportunity cost approach. The nutrient content of manure is valued based on the commercial fertilizer that manure can potentially replace (Nova Scotia Department of Agriculture and Marketing 2000). However, manure is bulky and generally low in nutrient concentrations. Table 1, Table 2, and Table 3 present the nutrient concentrations found in manure from different livestock. Cavers (1999) reported average nutrient value of manure tested in Manitoba and Saskatchewan respectively and their results support the general levels reported in Tables 1, 2 and 3.

Application of fresh manure on crop field may generate some adverse effects, so some researchers suggest that manure be treated before field application. Treatment of manure prior to field application may reduce pollution potential, maximize nutrient value and reduce odour (Danesh et al. 1999). Treatment processes can be classified into three general categories: physical, chemical, and biological.

Physical Treatment

Physical treatment involves solid-liquid separation. Separation of solids from animal slurries improves manure handling and storage properties and reduces the related environmental issues. Generally the solid part consists of 10-20 percent of the original volume of manure, so the smaller volume of solid can be spread directly or composted. Because of less organic matter, separated liquid manure will have less potential for the generation of odour during the storage and land application, and it can be pumped easily.

Solid-liquid separation can be accomplished by the use of sedimentation, screening, centrifugation, and pressing process. The sedimentation process is hindered when the amount of suspended solids in the wastewater exceeds 1%. Mechanical separators employing a wide variety of principles are normally used. These range from the cheapest static run-down screens, through medium cost (brush/roller screens), to the most elaborate (screw presses and centrifuge). Screens generally perform better with manure containing low total solids (less than 5%), while presses and centrifuges are more efficient with manure of higher total solids levels.

Concerted efforts to find better ways of controlling odour from manure are underway. Dietz (1999) argues that separating the solid from liquid makes manure both easier to handle and less offensive. At the University of Alberta, J. Feddes (personal communication), is working on applying the Alberta oilfield separation technology, using centrifugal force, for hog manure. Some farmers use a passive separation system, where manure is pumped from the barn into a cell. Before pumping, the manure is diluted to reduce odour. In this system, the largest solids settle out in the first cell, and the liquid overflows into a second cell (Dietz, 1999). The separated solids are compressed and stored in solid form, or composted. The composted solids have no odour at all (Vermette, 1999). The solution can then be applied to land through injection, to reduce run-off and volatilization of gases such as nitrogen.

Chemical Treatment

Chemical treatment processes are very efficient in dealing with some of the problems associated with manure. However, the use of chemicals may have some limitations, as they may generate their own specific problems. Furthermore, there can be considerable costs associated with both the chemicals and the related technology. The most common use of chemicals is for odour control. A wide variety of odour control products are available in the market. They are generally expensive, and their success and widespread use are still questionable.

Biological Treatment

Biological treatment processes are mainly intended to: i) reduce water pollution risks, ii) avoid odour generation, and iii) produce value-added products such as bio-gas or compost. There are two types of biological treatment: aerobic and anaerobic.

Anaerobic treatment

The more widespread anaerobic treatment systems for animal manure are anaerobic lagoons and anaerobic digesters. Anaerobic lagoons are popular in the warmer climates of Europe and Southern USA. They have low initial and maintenance costs and are easy to operate. The main drawbacks are the release of odours and ammonia from the large open surface area (specifically during spring and summer). However, this method is appropriate in these areas, where there is limited cropland available for manure application (Danesh et al. 1999).

Bio-gas, or methane, production through anaerobic digestion of organic matter may be an integral part of a combined manure management and energy production system (EPA, 1998). Manure is put into a controlled digester, where bacteria break down the organic matter in manure, and produce methane gas as a by-product. Methane can be used for heating or electrical power generation. The major advantages of this anaerobic treatment are the reduction of offensive odours, energy recovery, stabilization of organic substances, conservation of nutrients, reduction in emissions of greenhouse gases, and destruction of pathogens. However, this type of anaerobic treatment has not been adopted in Canada. This is due to relatively lower priced conventional energy sources, and a cold northern climate that requires a higher percentage of the energy produced, just to maintain the temperature of the digester (AAFRD, 1984). Other disadvantages include the high initial capital investment needed, and the higher level of management required produce methane. In a large-scale livestock operation, the installation of a digester, and day-to-day management of manure, may be difficult. Finally, these technologies require that the manure collection occur daily and have little straw or other bedding materials (EPA, 1998: Chapter 2). This would tend to preclude this an important technology for managing manure in the beef industry, which is the largest livestock sector in Alberta (AAFRD 2000-e), and the largest generator of manure in Alberta (Chaw and Abiola, 1999). This technology may be more applicable to dairy or swine livestock enterprises.

Aerobic treatment, or composting

There are a number of aerobic methods of manure treatment such as: oxidation ponds, aerated lagoons, and oxidation ditches. Composting is an enhanced aerobic and thermophillic biological process. In this process, microorganisms convert a combination of organic materials (such as manure, sludge, paper, food waste, and crop stover) into a humidified material. Although the process occurs naturally, by controlling the governing factors, this process can be greatly accelerated. Bedding material used in animal pens such as crop stover, saw dust, wood shavings, or straw, facilitates aeration.

Composting generates few offensive odours, reduces volume of manure, and reduces water content (thereby reducing the weight of manure). Many pathogens and weed seeds in the raw manure are destroyed. The compost produced from composting manure is often a high quality soil amendment and soil conditioner. The nutrients in composted manure are in organic form, suggesting a lower availability to plants. These nutrients are therefore less likely to leach into the ground water. Chaw et al. (1999) reported that, after 3 months of composting, a 60% volume reduction was observed for feedlot manure. Volume and weight loss during composting may increase the nutrient concentration of manure.

Composting of solid manure from feedlot and dairy cattle operations is relatively easy compared to hog manure, since hog manure contains a higher proportion of water. Two solutions are available for composting hog manure: separation of solid and liquid before composting (Chaw et al. 1999), and pen-on-litter, or *in situ*, composting (Tiquia et al. 1999). In this system, pigs are raised in pens, the floor of which is covered with a thick layer of sawdust. The sawdust is mixed with a commercially available bacterial product to aid decomposition. After 10-13 weeks, the spent litter is removed from pens, and composted in windrows to achieve full maturity. Frequent turning of manure during composting accelerates the composting process and enhances the quality of manure.

Methods of composting

Small scale on-farm composting can be carried out with minimal farm modification. Manure with bedding materials does not necessarily require further amendments, and can be simply composted by using actively aerated piles, that are periodically turned by a loader or tractor. Larger operations may need to invest in specialized composting equipment. Extensive *windrowing* operations may need to purchase a windrow turner. Alternatives to windrowing are:

i) *In-Vessel-Composting*: In this method of composting, composting can be done year round, irrespective of weather conditions. Weed seeds and pathogens are destroyed. Once constructed, operating cost is lower, because less labor and space is required to operate the turning equipment (Paul, 1999).

ii) *Vermicomposting:* Composting animal manure by using worms is called vermicomposting.

The decision to compost the manure and then apply it to crop fields, incurs additional costs that must be weighed against the fertilizer benefits of manure or compost. There should be enough of a decrease in hauling cost of compost, to capture the increased cost of composting. The potential end use of composting may dictate the type of composting process used. Potential markets for composting are greenhouses, nursery growers, organic farms, and other targets. Agricore, a Western Canadian cooperative, is developing a composting enterprise based on beef feedlot manure (Agricore, 2000). Agricore's target market appears to include golf courses and city playing fields, although Janzen (1999) reports that Agricore is also marketing this compost to grain farmers.

Despite its benefits, composting of animal manure has not been widely adopted in Alberta. Unlike the USA, the markets for finished compost are likely underdeveloped or limited. There would be greater incentive to compost if the finished product could result in additional revenue for the producer. The market for compost is likely directly related to the size of urban population. The waste-to-resource aspect of composting can only be realized if there are markets for product (Chaw et al. 1999; AAFRD, 1984). In addition, producer lack of knowledge concerning composting is cited as a reason for the low level of adoption of composting technology (Chaw et al. 1999).

Other Manure Management Techniques

Manure as a livestock ration

A large portion of nutrients ingested by farm animals is excreted in manure. Farm animals excrete 30-50 percent of the dry matter they consume. By recycling animal manure into animal rations, a protein supplement can be obtained. This will can in the growth or maintenance of the farm animal, and feed ration costs can be minimized. It is reported that re-feeding manure to livestock can reduce feed cost by as much as 25% (AAFRD, 1984). It was not clear from the one reference used here whether this practice is used presently or if it is even recommended.

Poultry manure has been shown to have a higher nutritional value than cattle or hog manure. Among the different types of poultry manure, broiler litter and caged layer manure have received the most attention for recycling feed supplements. Both types of poultry manure provide nutritionally acceptable, high quality protein supplements, which can be mixed with conventional feeds for use in ruminant growing/finishing rations. This may provide competitive, but cheaper, gains than the usual forms of protein supplement. Although cattle manure is lower in nutritional value than poultry manure, it has nutritional value as a ruminant feed.

Using the hog manure as a feed ration faces practical problems. Since most hog operations are set up for dry feed, and the separated material is a semi-solid, it is difficult to handle. An additional drawback is that the material cannot be stored because of putrefaction problems. Actual reduction of feed costs will depend on: a) the type of manure solids being used, b) how fresh manure is when it is collected, c) the quantity of manure that can be collected, processed and stored for re-feeding, d) the percentage that can be used in a re-feeding program, and e) the cost of collecting, processing and storing the solids (AAFRD, 1984). Other issues related to actual practice or health issues are not explored further.

Changing composition of feed ration

Interest in reducing the amount of nitrogen excreted by animals through improving diets and improving N utilization by the animals is increasing (Paul and Agassiz, 1999). A large portion of nutrients consumed by livestock is excreted in manure. It may be beneficial to formulate the animal feed ration in a way that ensures an increased feed conversion ratio, without affecting the growth rate of the animal. This issue has been examined in Europe (De Vos et al.)

Grandhi et al. (1999) carried out a feed ration experiment on swine at the Brandon Research Centre, Manitoba. Grandhi et al. (1999) compared the growth performance of swine, and level of nutrient excreted in manure in two feeding regimes. One feeding regime involved the feeding of hulless barley mixed with supplemental amino acids and Ronozyme-B enzyme. The other feeding regime involved the feeding of normal feed barley. Pigs fed with the hulless barley diet had higher apparent digestibility, retention of dry matter, and energy. There was about a 30% reduction in excretion of fecal dry matter, over the regular diet and a 28% reduction in excretion of nitrogen. No adverse effects on pig performance were reported. Grandhi did not directly address the economic cost or benefits of this alternative feeding program.

Changing the diet is one way to manage nutrient levels in manure and potentially reduce the overall impact of nitrogen and phosphorous on the environment. It can also reduce greenhouse gas emissions (De Vos et al.). This strategy would imply adding the manure nutrient contents as another constraint when formulating livestock rations.

Cover for manure storage

To minimize the nutrient losses through ammonia volatilization and nuisance odour from manure storage structures, different materials are being used as covers for manure storage. Straw covers for liquid manure storage have become relatively commonplace across western Canada. A disadvantage of straw is the tendency for the straw to become submerged over the summer, reducing its effectiveness. In addition, producers have expressed difficulty in pumping and handling manure from a storage facility that has been covered with straw. Floating plastic sheets can be used as covers. This practice is popular in the Netherlands. However, due to the high cost of the plastic cover, this method has not been widely adopted in Western Canada.

For solid manure, some form of cover could be used. These could include a roof, plastic cover, etc. The use of bedding materials such as straw, crop stover, wood shelving, or sawdust in animal barns will reduce odour and facilitate aeration, while manure is composted later.

A bio-filtration technique is used to reduce odour from manure storage pits of swine operations in the U.S. Bio-filtration is an air pollution control technology that uses microorganisms to break down gaseous contaminants. Bio-filters work well to reduce gaseous emissions (Nicolai, 1999). Although bio-filters were successful in reducing odours, they may not be cost effective.

Manure Production in Alberta

This review, using a very simplistic approach, estimated that more than 6.3 million tonnes of manure were generated in Alberta in 1996 (Table 4) and further details on this calculation are presented below. On a province-wide basis, there is adequate cropland area to make use of all the nutrients available in the manure produced in Alberta. Alberta has a total cropland area of more than 9.5 million hectares (Canada Grains Council, 1998) plus additional land in hay, pasture and range. Manure can provide some or all of the nutrients needed by crops if it is used in the proper amounts at the right times (Hilborn and Brown, 1996). These nutrients from manure include nitrogen, phosphate, and potassium. However, the uneven distribution of livestock populations in Alberta increases concern over the availability of a local land base for proper utilization of all the wastes generated by livestock.

Livestock population in Alberta, especially that of cattle, is growing faster than cropland area. Over the past 25 years, the number of cattle and calves has increased by about one third (32%) (CANSIM, 1999) which may also imply that manure levels have increased by the same percentage. Farmland has only increased by 5% (Statistics Canada, 1998 - Census Agriculture).

Manure production in high-density livestock areas has resulted in air, soil and water pollution. Chang et al. (1991) attribute this increase to there being proportionately less land base in the vicinity of intensive livestock and feedlot units. This has resulted in high manure application rates on nearby land. Manure is bulky and low in nutrient concentration (Grundey, 1980). Table 1 and Table 3 (Appendix A) show that it takes greater quantities of manure to obtain an equal fertilizing effect as obtained from chemical fertilizer (Hilborn and Brown, 1996).

The assumption that all nutrients supplied by manure are required may be unrealistic because nutrients in manure are not in the proportions needed by crops (Grundey, 1980). Based in part on these facts, Roka and Hoag (1994) cautioned that environmental regulators must be more vigilant, since producers may have economic incentives to apply excessive amounts of manure on land close to a storage facility. The results from Janzen et al. (1999) suggest this maybe the case in Alberta.

Manure production in Alberta varies among regions, divisions, and counties for climatic and geographic reasons. Higher livestock densities are concentrated in southern Alberta (Table 5). As reported by Chang et al. (1991), Freeze et al. (1985), and others, southern Alberta produces large quantities of manure and the local land base available for nutrient recycling may be a limiting factor. In Lethbridge, in 1996, 24,086 hectares (ha) received animal manure, of which 18,913 ha received solid manure, and 5173 ha received liquid manure (Statistics Canada - Census of Agriculture, 1996). As a general guideline, one *animal unit*, AU, of most animal species produces enough manure for one acre of corn (Hilborn, 1992). An animal unit commonly defines the average amount of forage consumed by a cow/calf production unit during a year as equal to 26 pounds of dry matter per day (McGinty, 1996).

Table 6 shows the conversion for different types of livestock numbers into *animal units*. The livestock figures for Lethbridge county estimate that its *animal units* are 124,359 (Table 7). If the population of animals remains constant throughout the year, according to Hilborn's (1992) general guidelines, this requires 124,359 acres (50,328 ha) of cropland[2].

[2] The manure application number must be used with care. The census numbers may not report all the manure area correctly. The number of steers and heifers may not be in beef feedlots all year round.

When compared with the actual land area reported treated with manure in 1996 in Lethbridge county, 24,086 ha (59,519 acres), these figures tend to confirm the previously stated high rates of livestock manure application to fields. Varying cattle feedlot populations during the year may change the above estimates.

Janzen et al. (1999) estimated the nitrogen produced from confined livestock and poultry manure at the municipal level in Alberta. This production estimate is compared to the estimated nitrogen removal by crops. For example, the Lethbridge region has a large surplus of nitrogen production from manure, relative to estimated crop usage. Further estimates from Janzen et al. indicate that manure is applied to relatively small areas in each census region in Alberta[3]. The application rate of actual nitrogen from manure sources far exceeds the recommended application rate from commercial fertilizer nitrogen. Janzen et al. estimate that in 1991 after adjusting for manure produced from extensive agriculture, and initial N and P losses from manure produced from intensive agriculture, 161,000 tonnes of nitrogen and 44,000 tonnes of phosphorous were excreted in manure. These nutrients needed to be collected and distributed in Alberta. Working backwards from their numbers, this suggests that approximately 10 million tonnes of manure at 50% moisture were produced, which needed to be collected and managed[4].

On a province-wide basis, Alberta produced approximately 3 million AU in 1996 (Table 4) on farm. One *animal unit*, or beef cow, as reported by AAFRD (1996), produces 2.1 tonnes of manure per year (Table 8). This figure does not account for the turnover in feeder animals observed in intensive livestock operations. Three million AU, based on Hillborn's (1992) guidelines, requires 3 million acres (1.2 million ha) of cropland for sustainable manure annual applications. In 1996, Alberta had more than 9.5 million hectares (23.5 million acres) of cropland. This figure does not include hay, pasture or rangeland. On a province-wide basis, this means that Alberta has more cropland than it needs for livestock manure application.

Lethbridge County, a livestock intensive region, may have produced close to 262,000 tonnes of manure or dry manure equivalent in 1996 (Table 7)[5]. Using a simple calculation, Alberta as a whole is estimated to have produced over 6.3 million tonnes of manure in the same year (Table 4). Details on how this manure tonnage was calculated are provided in Table 4. These manure production estimates are very approximate and are a lower bound on annual manure production. This review uses our simple manure production estimates as a check against the various numbers reported by the literature.

[3] The source of numbers used in this calculation on manure application is not cited in the paper.

[4] These numbers by Janzen et al. attempt to exclude manure production from range animals etc.

[5] Chaw and Abiola (1999) report one reference that estimated that manure production in the County of Lethbridge was 1,058,000 tonnes in 1992 with 685,000 tonnes from beef feedlot and poultry manure, and 373,000 tonnes of liquid manure from dairy and hog operations.

Manure Management Practices in Alberta

On-farm manure storage method, method of field application, and timing of manure application have environmental and economic implications. The common manure storage practices and methods of application are discussed The management practice employed determines the capital costs and annual operating costs of any manure management system. The manure management system also impacts on the plant nutrient contents of the manure.

Manure Storage

Farm size and the prevailing agronomic conditions dictate the methods employed to manage manure. AAFC (1998) reported that in the case of solid manure, most Canadian farmers pile up manure into heaps without putting a roof over it. Manure pack is the second commonly used method for storing solid manure. These two methods are the two methods used most commonly for storing solid manure by farmers in the Prairie region (AAFC, 1999; Koroluk et al. 2000). Other methods of managing solid manure include open pile with a roof; open pad without containment, open pad with containment and covered storage pad (Figure 1 in Appendix B).

For the storage of liquid manure, farmers use unlined lagoons, lined lagoons, open tanks, sealed covered tanks and tanks above slatted floors. To protect the environment, environmental regulations also require farmers to keep manure storage facilities a reasonable distance away from watercourses. In some states in the U.S., waste management regulations are tighter. In North Carolina, which accounts for about 60% of the hog inventory in the southern US, the state legislates a hog facility is to be located at not less than 1,500 ft. from the nearest residence and 2,500 ft. from the nearest school, church or other public facility (Laura and Zering, 1997). This practice is known as a setback.

Hog Manure

Approximately 90% of hog producers in Canada's prairie provinces store manure in liquid form (Koroluk et al. 2000). Unlined lagoon structures, and tanks below the slatted floors are the two most common storage methods. The majority of farms construct their storage structure more than 15 meters away from the nearest watercourse, and more than 30 meters away from any well used for domestic purpose (AAFC, 1999). This guideline is specified at the national level.

Earthen Lagoon Structure

The earthen lagoon is one of the most common practices of manure storage in the prairie provinces (including Alberta). It involves a series of shallow lagoons that provide storage times of weeks, or even months. Although it is the least cost method of manure storage, high nutrient losses and nuisance odour problems are two main problems associated with earthen lagoon storage systems. Nitrogen losses through ammonia volatilization, due to the large open surface area exposed to the environment, are also higher in this system.

Floor Deep Pit Method

Deep pits collect manure beneath a swine facility. While there is less management involved, these systems produce odour problems within the facility. Storage of large quantities of manure in under-floor deep pits is not a common practice because it is expensive and manure gases are a potential health hazard. However, for a livestock farm with a small herd size, this method could be one option for minimizing nutrient losses and adverse environmental impacts (Danesh et al. 1999).

Slurry Tanks

Slurry tanks collect and store manure above ground, from smaller pits within a facility. Though these systems produce less odour than deep pits, they have high fixed costs, and application (labor) costs. Nutrient content of manure stored in slurry tanks is higher than manure from earthen lagoon storage structures. Fleming et al. (1998) claimed that application of manure stored in slurry tanks ensures higher nutrient conservation, and the manure can be hauled moderate distances from the storage source. By contrast manure from lagoon systems incurs higher plant nutrient losses.

Despite the nutrient losses and nuisance odour from earthen lagoon structures, the majority of hog producers are still using these structures. The cost minimizing method of disposing of manure nutrients is an anaerobic lagoon. Another reason is that certain types of swine operations use lagoon effluent for flushing the farrowing barns, rather than fresh water. The production cost advantages of lagoon storage in these facilities likely outweighs the disadvantages of higher manure delivery costs (Fleming et al. 1998).

Cattle Manure

The majority of beef cattle and dairy cattle enterprises store manure in solid forms. The majority of Alberta's land base is classified as prairie and boreal plain eco-zone (Smith and McRae 2000). In these two eco-zones, storing solid manure in an *open pile without a roof* is the most popular method, followed by *manure pack* system (AAFC, 1999; Koroluk et al. 2000). These two manure storage methods incur a greater risk of surface water pollution through nitrate leaching and surface run-off of phosphorous. Air pollution through ammonia volatilization, and nuisance odours from the open surface of manure storage site are also problems with these storage methods.

Poultry Manure

Poultry producers use floor housing and cage housing systems. In floor housing systems, the manure mixes with the bedding materials to form litter. Litter is removed at the end of each cycle. In cage housing systems, manure falls into pits or on to conveyors. In pit systems, the manure remains in the barn until cleaning. The manure may be stockpiled until it is used in floor housing and deep pit systems. Conveyor systems allow more frequent removal of manure from the bird housing area. Manure from conveyor systems is stored in lagoons or concrete tanks.

Poultry manure is composed of higher amounts of uric acid, which is rapidly converted to urea and ammonia. After application, almost of 90% of the nitrogen is available to plants in the first crop year (Sommerfeldt et al. 1988). The high uric acid content of poultry manure also produces a greater risk of water and air pollution through manure storage.

Manure Application

Soil has limited capacity to hold plant nutrients. Manure applied either in fresh or composted forms releases nutrients gradually, so considerable amounts of nutrients remain in the soil. Manure application at the same rate per year may cause nutrient build-up in soil, and may lead to environmental pollution through surface run-off, soil erosion, and sub-surface nitrate leaching. Other impacts may be the build up of heavy metals in the soil (Grevers et al. 1999). Repeated application may exceed the capacity of the soil-plant system to absorb and recycle the nutrients supplied through the manure (Grevers et al. 1999). Repeated applications of beef feedlot manure in Southern Alberta leads to accumulation of phosphorus in the soil (Hao et al. 1999). Olson et al. (1999) recommended that the annual rates of manure application be less than 60 tonnes/ha/year, in the short run (3-5 years). However, much lower rates may be required if repeated annual applications are continued over a longer term (5-10 years). These manure application rates depend upon soil texture, nutrient requirements of plants, and nutrient content of manure. However Grevers et al. (1999) claim that the long-term impact of applications of liquid hog manure on the quality of soil and on the environment in Western Canada is not known.

The timing of manure applications also affects the amount of nutrients available for plant growth and nutrient leaching. Spring field application of manure, before seeding, ensures a greater percentage of nutrient availability to plants. Winter application of manure may lead to large amounts of nutrient lost in spring run-off (AAFRD, 1984). Approximately 50% of manure is applied in the fall in the prairie and boreal eco-systems, the eco-systems most prevalent in the prairie provinces (Koroluk et al. 2000)

Application methods

Field application methods determine the amount of nutrients available to plants and the level of environmental pollution, particularly ammonia volatilization and nuisance odour. Typical manure management on large livestock operations involves direct application of manure to nearby fields, after some form of stockpiling (Koroluk et al. 2000). In the prairie and boreal eco-systems, 89% of manure is solid manure application and 11% is liquid manure application (Koroluk et al. 2000). Raw manure has been valued for its ability to provide plant nutrients, and improve soil physical and chemical properties, by increasing soil organic matter. However, application of raw manure to crop fields may be discouraged because of the potential for introducing weed seeds, plant and human pathogens, and insect larvae (DeLuca et al. 1997). Other undesirable characteristics of using raw manure as a soil amendment include: i) relatively variable and unstable nutrient content (Nova Scotia Department of Agriculture and Marketing, 1997), ii) relatively higher level of water content which limits economic hauling distances, and iii) odour levels that can limit field applications near homes or communities. Therefore, broadcasting manure without incorporation results in higher nitrogen losses and increased odour problems (Hulgreen et al. 1999).

Incorporation of manure into soil after broadcasting, soil injection of manure, and use of irrigation run-off are the three methods of application for hog manure to reduce plant nutrient losses and odour problems. The problem with soil incorporation is that manure cannot be applied to standing crops. This further constrains the availability of land area and time of year for spreading manure. However, injection of manure requires a soil injector. Acquiring such equipment could be costly for farmers. Flushing by irrigation run-off can be used only in limited areas, or areas surrounding the livestock farm. Furthermore, nitrate leaching through run-off and odour pollution are still major problems with this method.

AAFRD (1996) provides farmers with guidelines to help them practice sustainable agriculture. In general terms, farmers do not realize the nutrient value of the manure because of improper timing or excessive manure application in some areas (Paul and Agassiz, 1999). Farmers are advised to apply manure when crops have the highest needs for nutrients, and at optimum rates for maximum growth and minimum environmental pollution (Palmquist et al. 1997). Chang et al. (1991) state that the current manure application rates in Alberta are too high for sustainable agriculture. They argue that this has resulted from the gradual release of nutrients by animal manure, especially that of cattle from repeated applications to the land base. Janzen et al. (1999) show there are large areas of Alberta that could sustain higher levels of manure application.

To be available to plants, nitrogen undergoes mineralization. This is a process in which nitrogen changes form from organic to inorganic. The rate of change varies over time. For instance, a decay series (or rate) of mineralization of 0.5, 0.2, or 0.1 means that, if given one tonne of manure with 60 kg N, 50% or 30 kg of nitrogen will be converted from organic to inorganic forms in the first year. In the second year, 20% of what remains (60 - 30 = 30 kg, or 6 kg) is mineralized. At the beginning of the third year, 24 kg of nitrogen remains to be mineralized. If 10% of it is mineralized in the third year, then 38.4 kg out of 60 kg of nitrogen will be made available to plants. 21.6 kg (or about one third of the nitrogen) remains in the soil.

This pattern of nutrient release from manure results in what Sommerfeldt et al. (1988) call a *Michaelis-Menton* curve (Figure 2 in Appendix B). Conversely, poultry manure releases nitrogen more readily, resulting in an almost straight-line curve (see Figure 3 in Appendix B for the swine curve). The reason is that poultry manure is composed of uric acid, which is rapidly converted to urea, and then ammonia. Both curves illustrate the amounts of manure that must be applied to maintain nitrogen levels at 225 kg/ha/yr, 150 kg/ha/yr, and 65 kg/ha/yr. Failure to take into account residual nitrogen in the soil from previous applications may result in overloading, even after moderate applications. Olson et al. (1998) reported N accumulation in both medium-textured and coarse-textured soils after 120 and 180 kg/ha were applied on separate fields. This will require year by year field records. The key implication is that any economic evaluation of manure based on nutrient value should include this dynamic aspect of manure interactions with soil.

Application Rates by Soil Types

Manure application rates depend on factors such as soil absorption capacity, the available (ammonium) nitrogen level of the manure, the residual nitrogen level of the soil, and the expected nitrogen level of the soil (Palmquist et al. 1997). AAFRD has provided manure users with information necessary for improved manure management. Table 9 in Appendix A gives the assumed crop nutrient requirements for determining land base guidelines.

According to Table 9, nitrogen requirements increase from 56 kg per hectare for dark brown soil to 112 kg per hectare for irrigated soil (reading from left to right on the table). Phosphorous requirements also increase from dark brown (22 kg per hectare) to irrigated soil (50 kg per hectare). Potash requirements begin at 11.2 kg per hectare for dark brown soil, and hold steady at 17 kg per hectare for grey, black, and irrigated soils.

The land manure application rate recommendations are determined by the nitrogen requirements of the crop, less the amount carried over from previous applications (AAFRD, 2000-a). It must be noted that manure application based on crops' nitrogen needs could lead to over- or under-application of phosphorus and/or potash. Crop requirements under such conditions could be met by combining manure and commercial fertilizer.

Tables 10 and 11 (Appendix A) provide the land base guidelines for farmers to determine the amount of manure that can be applied to cropland. The tables are based on average soil fertility levels in the four soil zones and manure nutrient from typical production systems (AAFRD, 2000-a). Soil fertility and texture variability within soil zones, variations in manure nutrients, specialized crop types, and/or rotations were not considered.

Application rates for hog manure and beef feedlot manure are found in Tables 12 and 13 (Appendix A) respectively. However agencies recommend a soil test be conducted on the target land to make proper use of these tables (AAFRD, 2000-a). The crop requirement, less the soil available nitrogen, will give the amount of nitrogen that may be applied as manure and/or commercial fertilizer. Manure application rates are then based on crop nitrogen requirements.

Effects of Manure on Soil Types

One important consideration when choosing a manure management strategy is the effect of manure on the soil type. Alberta has different soil zones. The common classes are black, brown, and grey. This literature review found several studies on manure applications on soils in the Lethbridge region of Alberta that evaluated crop response to manure applications. The results are summarized in each case in Appendix C. The general conclusions from these studies are:

- Repeated manure applications above 30 tonnes/hectare/year (wet weight) to non-irrigated soil or above 60 tonnes/ha/year to irrigated soil did not increase crop uptake of nitrogen on clay type soils in the Lethbridge region. Little evidence of nitrogen losses from leaching, denitrification, or ammonia volatilizations were found under dry land conditions, but were found under irrigation. (Chang and Janzen, 1996).
- Repeated annual applications of cattle feedlot manure above 30 tonnes/ha (wet weight) to non-irrigated soil depressed barley yields, but did increase protein content (Chang, Sommerfeldt, and Entz, 1993). Soil salinity increased with increasing rates of manure application but did not affect barley yield. Barley yield on irrigated soils treated with similar or higher manure treatments did not show reduced yield.
- Repeated applications of manure of 30 tonnes/ha/year or higher increased soil phosphorus. The amount of soil phosphorus increased with increasing rates of manure application. (Dormaar and Sommerfeldt, 1986; Dormaar and Chang, 1995). There may be interactions between phosphorus and micronutrients such as zinc or copper (Janzen et al. 1993; Eghball and Power 1994; Chang et al. 1994, Chang et al. 1991).
- Higher ratios of carbon to nitrogen in the manure may reduce the initial crop benefit of application of manure to soils and eroded soils (Larney and Janzen 1996). For example, cattle manure mixed with wood chips has a higher carbon to nitrogen ratio than other types of cattle manure.

The results above indicate the on-site and off-site impact of manure applications vary by the type of manure and by the type of soil. These interactions need to be considered when evaluating the economics of manure management.

Proposed Regulations for Intensive Livestock Operations in Alberta

Manure management is one aspect of livestock production where economic, environmental, and social concerns may be compromised (Beck and Brown, 1999) or in conflict. Livestock operations in Alberta are governed by the 1995 Code of Practice for the Safe and Economic Handling of Animal Manure. This succeeded the 1982 Confinement Livestock Facilities Waste Management Code of Practice. However, AAFRD has proposed a comprehensive regulatory framework for intensive livestock operations. When this comes into effect, it will replace the existing Code of Practice.

The proposed document is currently under review by the Minister of Agriculture, Food and Rural Development, pending its approval. Like the 1995 Code of Practice, it intends to direct the establishment and management of intensive livestock operations, assists producers in minimizing the potential for nuisance and environmental problems, and improve manure management plans. The proposals in part highlight the concerns such as leaching, rates of application, nutrient loading in the soil and water contamination. More details on the proposals are in Appendix D. Of particular interest from the proposals may be the recommended manure application rates by soil type.

The proposed livestock regulations appear to use two main guiding criteria to determine the level of manure application. These criteria are (1) to avoid overloading the soil with macronutrients, in particular nitrogen and (2) to avoid offsite environmental impacts to water or nearby residents. Therefore any economic evaluation of manure and its benefits at the farm level needs to consider these two environmental criteria when doing the analysis. These issues have already been identified in earlier discussions, and would enter the economic decision framework as constraints on the business. Other issues that are identified in the proposed regulations include the location of the livestock enterprise, size, time of year, and weather. These are relevant considerations when evaluating the economics of manure management in Alberta.

Economics of Livestock Manure

Animal agriculture in developed countries has undergone significant structural change. Animal production has changed from rangeland production to concentrated, or intensive, animal production. A major factor motivating intensive livestock production is "economies of scale," through which the livestock and poultry sectors have been able to reduce their marginal cost of production (Laura and Zering, 1997). Technological innovations have made it possible for the livestock enterprise to capture the economies of scale. The livestock and poultry industries continue to concentrate increasingly both at farm and post-farm levels. Some of the innovations which serve as the driving force behind this structural change include productivity enhancing technologies, precision mixing of feed rations, and genetic improvement (Purvis and Outlaw, 1995). However, the simple economics of manure management through recycling (through the soil) may lead to farm managers who overload soil near the intensive livestock operation. The environmental costs of this overloading are typically paid by others, who are not directly associated with the livestock operation (Innes, 1999).

The animal industry in Canada makes a significant contribution to the Canadian as well as Alberta's economy. In 1999, the industry accounted for $14.0 Billion (Agriculture Economic Statistics, 2000); approximately 1.5% of the 1999 GDP (CANSIM[a] - SDDS 1901 STC 13-001, 2000). Although the industry's production value fluctuated between 1990 and 1999, it has exhibited an upward trend (Table 14).

The livestock sector accounted for $3.9 Billion, which represents 59.3% of total farm receipts generated in Alberta in 1999 (AAFRD 2000-a). This value represents almost 28% of the nation's livestock value or 0.4% of GDP in 1999 (CANSIM[a] - SDDS 1901 STC 13-001, 2000). Beef cattle are Alberta's largest farm cash earner. Farm cash earning due to beef cattle has almost continued to grow steadily over the nine-year period between 1990 and 1999 (Table 15). The livestock industry in Alberta is very important to the agricultural economy.

Nutrient Value of Manure

Manure's richness in plant nutrients has made it appealing as a fertilizer in crop production since the beginning of agriculture (Grundey, 1980). Until modern times, animal production has been a pastoral enterprise where animals spread dung on rangeland while grazing (Hopkins et al. 1991). This continues to be the primary way that manure is managed in developing countries today. Rangeland grazing is also practiced in developed countries. For the 1996 agricultural census, Alberta had up to 15.6 million hectares of natural land for pasture (Statistics Canada, 1996). Rangeland production ensures wide distribution of manure, making it less likely to affect soil or water quality.

Nutrient value is one way to value manure. Given this assumption, a value can be placed on manure. In 1996 Alberta's estimated 3.0 Million *animal units* produced over 6.3 million tonnes of manure, with a total value of more than $40.2 Million (Table 16). This value is based on the manure production rate of 2.1 tonnes per *animal unit*. It is important to note that, the value of manure varies between (as well as among) animal species (Table 2 and Table 3). The price rates of N - $0.28/lb, P_2O_5 - $0.37/lb, and K_2O - $0.17/lb are those used by Alberta Agriculture Food and Rural Development. Table 16 shows the estimates of Alberta's economic value of nutrients in feedlot manure (AAFRD, 2000-a). To arrive at the total value in column five of Table 2, an assumption made here (as well as during the estimation of Alberta's 1996 manure-value) is that all N P_2O_5 and K_2O are necessary for crop growth. Values were not placed on any other nutrients found in the manure.

Using Janzen et al. (1999) estimates of nitrogen (161,000 tonnes) and phosphorus (44,000 tonnes) annual production in Alberta needing to be "managed" suggests a rough nutrient value on manure produced annually in Alberta of $82.4 million for the phosphorus and $99.2 million for the nitrogen[6]. This is far higher than the simple estimates calculated in Table 16 but is similar to the estimate quoted in Bolten (1999) of $164M and $159M for N and P respectively for the value of manure produced in the prairie region. Using data from Nagy et al. (1999) that values the N and P from beef feedlot manure at approximately $9/tonne (wet basis), and the quote from Bolten, would suggest that 36 million tonnes of manure are produced on the prairies[7]. The apparent confusion in total manure production may be related in part to the percentage of moisture assumed to be in the manure.

On Farm Manure Costs

Grusenmeyer and Cramer (1997) discussed efficiency in their "systems approach" to manure management. They stated that manure that accumulates, instead of being used to add value to an operation, is a nutrient loss (cost) to the operation. As farmers attempt to control nutrient flows and transformations on-farm, the costs of their systems increased. The authors suggested that when the environment is at risk, producers are forced to accept increased costs, in order to minimize hazards. Fulhage (1997) also noted that the costs of owning and operating manure management systems should be included in financial analyses, when considering herd expansions. The author stated that economies of scale in dairy operations could decrease the cost of manure management on a per unit basis.

Innes (1999) discussed the economics of manure management in simple terms. Transporting manure to distant fields is generally too costly for farmers. Therefore, manure is spread on fields surrounding an operation. The reasons given for this are: a) manure replaces expensive chemical fertilizers, and b) manure application can be costly, and c) the cost increases as the distance from manure storage to field increases. Hence, the marginal cost is lower for manure applied to fields close to an operation. However, the author noted that marginal nutrient benefits of manure application (for a specific field) decrease as the number of applications increases (Figure 2, Appendix B illustrates this concept presented by Innes, 1999). This means that a farmer will continue to apply manure to closer fields, until the marginal nutrient benefits of distant fields outweighs their higher delivery costs. There may be a direct conflict between cost minimization at the farm level, and off farm environmental impacts of higher manure application rates.

Different storage and management methods have been previously mentioned. Each of these methods has specific costs associated with it. The same can be said for the various methods of application (when manure is used as a fertilizer). In both cases, there are costs associated with machinery, storage facilities, and labour. Nagy et al. (1999) also noted costs associated with the hauling of manure over varying distances. The following sections will analyze various studies that have been performed regarding the costs associated with manure management. Where possible, details of studies are given. Table 17 (Appendix A) shows cost comparisons of United States (for reference purposes) for different manure management

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[6] This is calculated as follows. For P, 44,000,000 kg x 2.3 x $0.37/lb x 2.2 lbs/kg= $82.4M where 2.3 converts P to P_2O_5 and for N, 161,000,000 kg x $0.28/lb x 2.2 lbs/kg = $99.2M

[7] ($164M + $159M)/$9 per tonne=36 M tonnes.

systems. The following discussion begins with recommended approaches for doing on-farm investment analysis.

Investment Analysis And The Economics Of Manure

The prior discussion on the science of manure and the economics of manure has highlighted many separate aspects of manure and its implications for livestock producers in Alberta. There are environmental impacts. There are societal impacts. There are on-farm impacts. There are complex interactions between manure, soils and crop production that occur over time but may not be well understood by researchers. The literature review above and below generally identified one overall approach to evaluating the economics of manure when viewed from the perspective of the farm managers. Generally this is a static approach or deterministic evaluation of the costs and benefits[8]. Schnitkey and Miranda (1993) included some dynamics in their math model but the approach was still deterministic. Stonehouse and Narayanan (1984) used a linear programming approach to determine optimal manure management in a mixed livestock-crop farm in Ontario. These static economic approaches already reviewed and discussed below can further be categorized into combinations of four general approaches. These are:

- Opportunity Cost: Value the nutrient content of manure using commercial values and consider the manure or manure product as a commercial fertilizer substitute or supplement. The additional soil benefits are more difficult to quantify.
- Crop Benefit: Value the direct crop benefit by comparing soil with manure applied versus a control with no manure applied. Yields and crop prices are included in the analysis and it attempts to indirectly price the additional soil benefits of manure application.
- Cost of Business: Views the manure exclusively as a by-product of livestock production and evaluates methods for minimizing the cost of disposal.
- Business Enterprise: Manure production is a value-added business and a separate business enterprise approach such as employed by Agricore for commercial sale of compost or as advocated by Janzen (1999) is employed.

The above four approaches may or may not explicitly incorporate environmental or societal constraints in the analysis. Many of the economic evaluation approaches reviewed in this study use simplistic financial or capital budgeting analysis techniques. An exception to these prior two criticisms may be Stonehouse and Goss (1999). They state that their model for on farm decision making about manure systems incorporates environmental, societal (such as odour or disease risk from manure), technical and economic components. The economic component appears to be consistent with Net Present Value (NPV), a preferred investment analysis approach when dealing with investment decisions from a static viewpoint[9]. Methods for evaluating on farm investment or benefits of manure in a static framework are presented next.

There are a number of methods available to analyze investments. In the case of manure management, a producer must invest in capital that will have value for more than one

[8] Freeze et al. (1993) used simulation to evaluate the economic hauling distance for beef feedlot manure applied to highly eroded soils. Their results suggested that a "positive" breakeven hauling distance to eroded soil in the range of 20 to 29 kilometers soil 70% of the time in their simulation. Janzen (1999) refers to computer simulation models used to evaluate investment in manure processing.

[9] Stonehouse and Goss (1999) do not clarify if their decision support model is deterministic or stochastic.

period. In order to analyze potential investments in management systems, a producer should adjust future income and expenses to reflect when they will occur (Lybecker, 2000). That is, the time value of money must be taken into consideration. The time value of money is one of the most important concepts in corporate (and farm) finance (Ross et al. 1999). One can look for the future or the present value of money. Lybecker stated that, if you invest a certain amount of money at a specific interest rate, its future value will be more than the amount invested (e.g., $909.09 invested for one year at a 10% interest rate, will have a future value of $1000 in one year). Computing a future value is done through the process of compounding (Lybecker, 2000). In this case, the interest rate is also called the compound rate.

Present value describes the value today of a sum of money to be received by a person in the future, at a specified interest rate (Lybecker, 2000). That is, how much would a person have to invest today, in order to receive a certain sum at a future date? Contrary to the compounding process used in future value calculations, present value relies on the process of discounting. Instead of an interest (compound) rate, a discount rate must be used. Lybecker (2000) noted that both compounding and discounting could be applied to a sum of money, or a stream of payments (such as an annuity). These practices can also be applied to enterprises that have a life longer than one year. The analysis of these enterprises is called capital budgeting. The discounted value of expenses and revenue over the life of an enterprise is called Net Present Value (NPV) (Lybecker, 2000).

In order to understand the computation of a NPV, a simple example adapted from Ross et al. (1999) will be used. A company has the choice of investing $100 in a riskless project. The project has one cash flow of $107 after one period. The company can choose to invest the $100 today, and pay the $107 as a dividend after one period. On the other hand, the company can forego the project, and pay out the $100 as a dividend now. The interest rate is 6%. The NPV of the project would be calculated by dividing the $107 dividend by 1.06 (interest rate), then subtracting the $100 initial payment. The result is 0.94. When an NPV is positive, a company will generally accept a project (Ross et al. 1999).

The above example could be applied to many situations. A farmer faces a variety of investment decisions that affect his or her operation. The NPV method has three main attributes. The first attribute is that NPV uses cash flows. Other methods use earnings, which are artificial accounting constructs (Ross et al. 1999). Earnings do not represent cash, as cash flows do. NPV also uses all of the cash flows of a project, instead of ignoring cash flows after a specific period (as other methods do). NPV analysis also discounts cash properly, relying on the time value of money (Ross et al. 1999). Concepts used in determining discount rates for NPV analysis are beyond the scope of this paper.

Other than NPV, there are a number of methods that are used to analyze investments. Ross et al. (1999) refers to these methods as rules. Payback, accounting rate of return and internal rate of return (IRR) are briefly discussed in Appendix E.

NPV is a better approach for investment analysis. However, many businesses (including farm businesses) often use the accounting approach or IRR to evaluate choices. Future analyses of manure management would benefit from NPV analysis or more dynamic analysis.

Liquid and Solid Manure

Based on the key plant nutrient content found in manure, several studies claim manure can only be transported a short distance from the original source before transportation costs exceed the plant nutrient value of the manure. Freeze and Sommerfeldt

(1985) argue that beef feedlot manure can only be transported 18 kilometers from the source beyond which point the transportation costs exceed the plant nutrient value found in manure. However, Janzen et al. (1999) argue that if the total crop benefit is included in the calculation, then manure (not necessarily feedlot manure) can be transported up to 300 kilometers. The Janzen et al. (1999) study is based on a 'steady state' model and proposes that it can be economical to distribute manure as far as 300 km from the source, especially when dealing with high value crops. The study uses the approach of estimating potential crop benefits from the application of manure. It assumes agronomic conditions where only the amount of nutrients required by the crop is supplied. Under these conditions, the study concludes that with good management, nutrient conservation and distribution is feasible and may enhance profitability of crop production (Janzen et al. 1999).

Nagy et al. (1999) studied a hog operation, which utilized a 19,749,000 litre lagoon. Their study focused on two sites, Dixon and Burr. These sites were located in the black soil zone, in eastern central Saskatchewan, near Humbold, and studied over two years. Costs were calculated based on varying application rates at the two sites. In addition, calculations were made based on whether or not the producer owned the equipment or not (i.e., custom spreading). It was found that, at lower application rates per hectare, custom spreading was cost effective. At higher application rates, it was economical for a producer to own the equipment used for application (Table 18). Details on how fixed costs were allocated were not discussed and the custom versus owned results should be used with caution. The manure was also valued based on the total nutrient content (nitrogen, phosphorus, potassium, sulfur, copper, magnesium, zing and iron). For example, 38,138 liters per hectare of liquid hog manure had a total nutrient value of $52.42/ha in 1997 or $39.88 for just the nitrogen and phosphorus. Nutrient values were determined based on commercial fertilizer costs.

There are at least two problems with valuing manure based on plant nutrient content. Manure nutrient content varies and a nutrient only has economic value if it is required or needed. An alternative method for valuing manure compared the crop net revenue/ha with manure application to the crop net revenue with no manure or commercial fertilizer application. Using this calculation, the economic hauling distance ranged from 0 to 13 kilometers depending upon the year, actual yield, crop price and "optimal" rate of manure application (Nagy et al. 1999)[10]. This method of valuing manure ignores the ability of crop production managers to vary or substitute the source of crop nutrient inputs to maximize expected profits.

Nagy et al. (1999) also evaluated a cattle operation. Calculations for handling costs were based on manure production of 9,490 tonnes per year. As in the liquid manure example, the authors used varying rates of manure application on two separate sites, Dixon and Burr. Custom application was economically feasible, using lower rates of application. As application rates per hectare increased, it was found that a producer could own his or her own equipment (Table 19). Details on how fixed costs were allocated were not discussed and the custom versus own data should be used with caution. The manure was also valued based on total nutrient value. In 1997 for example, 9.7 tonnes/ha had a total nutrient value of $209.20/ha or $83.39/ha for just the nitrogen and phosphorus. An alternative method for valuing manure compared the crop net revenue/ha with manure application to the crop net revenue with no manure or commercial fertilizer application. Using this calculation, the

[10] It is not clear to the reviewers how the marginal rate of return was calculated and how this in turn was used to determine the best rate of manure application based on yields, costs and prices.

economic hauling distance ranged from 1 to 8 kilometers depending upon the year, actual crop yield, crop price and "optimal" rate of manure application.

Despite possible shortcomings in the economic analysis, the study by Nagy et al. (1999) clearly indicates that cost of handling, hauling and incorporating manure, which is directly related to volume, is a key component in evaluating the economics of manure. Another key component in the economic value of manure is the nutrient content and how crops respond to this source of nutrients. Nagy et al. (1999) also indirectly tried to evaluate the multi-year economic impact of manure applications to crop-land. Economic analysis of manure application that includes "benefits" needs to consider the multi-year impacts. Nagy et al.'s (1999) nutrient valuation places the total plant nutrient value of beef feedlot manure at $21.57/tonne or the N and P nutrient value at $8.60/tonne. Their estimated cost of manure handling was around $8.40/tonne for selected sites. Based on total nutrient value there is a net benefit to applying manure if all the nutrients are required by the soil however there is a almost a zero net benefit of applying the manure if only the N and P nutrients are required by the soil.

Roka and Hoag (1996) combined manure nutrient value with the optimal swine production decisions for a representative swine finishing operation in North Carolina. The manure was applied to nearby land subject to environmental regulations. Their mixed integer systems model showed that even under the most favourable conditions the net benefit of manure was -$2.94/head (US$) marketed. The costs of treatment and transport of the manure were greater than the fertilizer replaced. Thus manure is a net cost and not a net benefit to the business. This provides economic incentives for intensive pork operations to over-apply fertilizer on land nearest the storage facility. Their other conclusion was that even when the cost of the manure is included, it has little impact on the optimal production plan for the animals.

De Vos et al. reviewed several studies on the economics of manure handling systems. One 1982 study, a survey of Ontario swine farms, found that costs ranged from $7.70 per 1000 gallons for a tanker-broadcast system to $11.30 per 1000 gallons for a tanker-injection system[11]. De Vos et al. also provide references on European studies reducing ammonia emission in swine operations. Their conclusions were that ration adjustments which reduce excess nitrogen may be cost effective. However, reducing nitrogen excess through improved manure handling and storage was much more expensive per unit of emissions reduced.

Hilborn and Brown (1996) demonstrated how considerable savings could be derived from a 50-cow dairy herd, plus young stock. They argued that this herd produces approximately 500,000 gallons of manure a year; containing about 7,000 pounds of nitrogen, 3,500 pounds of phosphate, and 15,000 pounds of potash. If it is applied according to a nutrient management plan, this manure could replace $6000 of commercial fertilizer (Hilborn and Brown, 1996). This does not include the application costs.

A systems model for dairy also shows a net cost for managing the manure (Borton et al. 1995) even when integrated with a crop enterprise. Net costs per cow range from -$70 (US) for a semi-solid manure system with daily application to soil to -$241 ($US) with six month storage lagoon and soil injection application (Table 20). The costs increased with smaller dairy herd sizes and with more investment in long term manure storage facilities. Again, one key conclusion is that manure is a net cost to the business. De Vos et al. in their

[11] De Vos et al. refer to an unpublished study by Fleming and Stoner (1982). Comparison of 3 systems of Spreading Liquid Manure. Unpublished report presented to OMAFRA.

review discuss a 1995 study that also evaluates manure management in dairy barns in Ontario[12]. The least cost system using an analysis combining "opportunity cost" and "Cost of Business" found that an alley flush collections system with storage in three earthen lagoons and application with a hose reel irrigation system the preferred system. The net annual costs for a 250-cow herd for the alley flush system were $130/cow and the earthen lagoon could cost as low as $2/cow. Concrete storage was up to 10 times more expensive.

Rausch and Sohngen (1999) compared three typical handling systems in Ohio for Dairy[13]. This Ohio study presented below also uses the accounting investment analysis. These were, respectively, an earthen holding pond using drag-line direct injection (liquid), an earthen holding pond using a liquid tanker, and a stack pad using a conventional spreader (solid). Each system was designed for an 80-100 cow dairy. The authors' goal was to compare the costs and benefits of each system. Their approach is consistent with the "cost of business" approach. However, as discussed below, their investment analysis could likely be improved.

The two liquid systems were identical in their structural characteristics (Rausch and Sohngen, 1999). Both systems scrape manure into a reception pit, where it is held until it flows by gravity to the holding pond. All milk house waste and feedlot run-off is diverted into the holding pond, increasing the capacity requirements of the holding structure (Rausch and Sohngen, 1999). These structures typically cost about $2.50 (US) per cubic yard of volume to build. In Rausch and Sohngen (1999), the annual rate of interest was 8% and the life expectancy for these structures was 25 years.

Equipment requirements for the two systems were similar. Both systems required three tractors and a chopper pump to move manure into and from the structure (Rausch and Sohngen, 1999). The drag-line system required an injection toolbar (as well as irrigation equipment) for continual operation during periods of manure application. The liquid tanker system used a typical liquid manure spreader for land application (Rausch and Sohngen, 1999). Each of these systems used about the same amount of labor each year. However, the drag-line system required additional labor to set-up, tear-down and monitor the irrigation line during land application.

When comparing costs and benefits, Rausch and Sohngen developed Quattro Pro spreadsheets, which could be used to calculate specific costs and benefits for each system. Their spreadsheets used an accounting approach, with values chosen according to data collected from various farming operations. In summation, each method resulted in a net cost to producers. The cost of the solid stack system was $3,785/year. The liquid tanker system would cost an operator $8686/year. For the liquid drag-line system, the cost was $11,766/year. In the previous section, it was noted that the NPV method was preferred over accounting approaches, for a number of reasons. If Rausch and Sohngen's model were to be improved, cash flows would have to be determined for each system, over a number of years of operation. A discount rate for the project would also be needed. Then, an NPV analysis could be applied.

Stonehouse (1998) evaluated the economics of manure handling systems on six farms in Ontario. The methodology appears to be consistent with NPV. After accounting for capital costs and the fertilizer nutrient value of the manure, the net benefits ranged from

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[12] De Vos et al. reference Lazenby, M.T. (1995) A Farm Level Evaluation of Four Liquid Manure Management Systems For Freestall Dairy Operations in Ontario. MSc. Thesis. University of Guelph, Ontario.

[13] Spreadsheets showing their analysis are available at their website.

$0.06/tonne to -$124.28/tonne of manure applied each year. The high cost farms in the case study were associated with research farms. Costs for the commercial farms are reported in Table 21. One case study farm showed a net benefit of $0.06/tonne of manure applied annually (Table 21). Stonehouse (1997) concluded that solid manure handling systems were more expensive than liquid manure handling systems and annual ownership costs far exceed annual operating costs. Stonehouse's conclusions regarding solid waste being more expensive than liquid waste should be interpreted with caution, since a common unit for measuring manure (such as dry weight) was not provided. Off site costs, long-term soil impacts and other related issues were not included in the analysis.

Schoenau (2000) argues that valuing the nutrient content of manure based on commercial fertilizer values is too simplistic. The release rates, crop benefit and other factors need to be included in the calculation. Schoenau reports that the economic hauling distance in Saskatchewan for swine manure (at 3300 gallons per acre/year) is 8.3 kilometers, and for cattle manure (10 tons per acre per year) it is 3.3 kilometers. The economic hauling distance reported in the research literature is quite variable and the analytical approaches used by researchers varies.

Composted Manure

Another option available to producers is composting, which reduces the volume of the manure. Composting reduces transportation cost but increases the cost of handling manure. This practice was described in detail in previous sections. MacNeil and Sawyer (1999) obtained data on American composting systems, which is presented here for comparison purposes (Table 22). Agricore (2000) claims that composting of beef feedlot manure transforms two tonnes of manure to one tonne of compost.

Freeze et al. (1999) proposed composting as an alternative to conventional manure management practices, in areas where intensive livestock operations are highly concentrated. Land that is nearby, and suitable for further manure application, is a limiting constraint. Transportation cost of manure to distant sites is costly. Alternative markets for manure based on compost, such as those being developed by Agricore (2000), may be limited. An experiment was performed, which compared composted beef feedlot manure from pens bedded with either wood chips or straw. The manure was windrowed, and turned over a three-month period with a tractor-drawn windrow turner. Freeze et al. (1999) noted that increased costs over manure included hauling to the compost site, costs associated with maintenance and turning of windrows, and loading the compost for transport to a field site. This analysis by Freeze et al. (1999) treats manure as a cost of running the beef feedlot and evaluates methods for minimizing this cost.

Freeze et al. (1999) calculated the costs of their proposed composting system. Their study used an accounting approach to evaluate beef feedlot composting using a "cost of business" approach. The total costs were calculated at two different labour rates, $8/hr and $12/hr, and based on 183 tonnes of straw manure (before composting) or 207 tonnes of wood chip based manure (before composting). The 65 tonnes of straw-based compost produced would cost $8.37/tonne at a $12/hr labour rate to compost. The 85 tonnes of wood-based compost produced would cost $7.11/tonne to compost (Table 23). At an $8/hr labour rate, the 65 tonnes of straw-based compost would cost $7.48/tonne, and the 85 tonnes of wood-based compost would cost $6.36/tonne (Table 24).

Freeze et al. (1999) also compared the hauling costs of compost to those for manure. Once again, two labour rates ($8/hr and $12/hr) were used in the calculations. The authors also compared three hauling distances, 5km, 12.63 km, and 40 km. On a total cost basis, at either labour rate, straw-based compost had the lowest hauling costs. This was followed by wood-based compost, straw-based manure, and wood-based manure (Tables 25 and 26), relative to the original volume of manure. The results suggested that compost-hauling costs might make up for the added costs of composting over manure, when distance was factored in. Freeze et al. noted that 13 km was the approximate least distance compost would be hauled (compared to manure) to allow a producer to capture enough decreased hauling costs to cover increased composting costs (mentioned previously). This analysis by Freeze et al. (1999) did not factor in the nutrient benefits or loses associated with compost and only explored the costs of composting and transportation costs.

One of the main reasons for the hauling-cost advantages of compost would be its lower weight (relative to the original manure weight) and higher dry matter content (compared to manure). These characteristics suggest that more compost could be transported at one time relative to the original manure volume, cutting down on total travel time. Freeze et al. (1999) suggested that spreading time for compost was also minimized. Freeze et al. calculated per cent dry matter content, moisture (% wet weight), as well as nutrient levels for compost. Highlights can be found in Tables 27 and 28. Clearly, nitrogen was lost during the composting process.

Composting animal manure could be a possible manure management alternative for livestock operators in Alberta (particularly hog and feedlot operators). With significant decreases in volume and weight of manure upon composting, nutrient value of compost manure may offset the composting and hauling cost. Compost manure releases plant nutrients gradually, so the nutrient value could be spread over several crop years. Composting reduces volume of beef feedlot manure by up to 80%. However, composting resulted in nitrogen losses of 32% and carbon losses were 68% (Larney and Carcamo 1999). Larney and Carcamo (1999) report macro nutrient contents for composted beef feedlot manure at Lethbridge. However other researchers indicate that the benefit of the volume reduction due to composting may be offset by the nitrogen loss during composting (St. Jean, 1997)[14]. Furthermore, besides plant nutrients, compost manure has other beneficial effects on soil, such as: improving soil tilth, building up organic matter, improving physical properties of soil, etc. Such benefits are not easily quantified in monetary terms.

Information is lacking on economic hauling distance of the composted manure of different animals. Since the cleaning of pens and loading activities must be done whether the producer decides to compost or not, costs associated with these activities should be considered as *sunk costs* (Freeze et al. 1999). Additional costs of composting include manure incorporation cost, hauling cost, and maintenance and turning of windrow piles. If producers want to acquire a windrower, to assist with the composting activities, the enterprise will incur additional capital cost. Freeze et al. (1999) stated that much research has yet to be done on manure composting.

Other Costs

In recent years, the perception of the public has become an important factor when considering manure costs. The ERS (1996) referred to a lawsuit brought against *Southview*

[14] St. Jean (1997) reports on research indicating that composting of dairy manure results in a net benefit from reduce spreading costs of $0.41/T (wet) manure composted after accounting for N loss but for poultry manure the net loss of N exceeds the reduced spreading costs by $5.01/tonne (wet).

Farms in 1994 (Concerned Citizens vs. Southview Farms) in the United States. The lawsuit argued that the operation be designated as a Confined Animal Feeding Operation (CAFO). CAFO's come under the jurisdiction of the EPA's Clean Water Act (CWA) (Innes, 1999). It was ruled that the farm was a CAFO, and that its manure operations made it a "point source" of pollution (ERS). Until this lawsuit, the farm had not been considered a CAFO.

The ERS also reported on a nuisance lawsuit brought against *National Farms Incorporated* by a Nebraska couple. The case against the farm stated that the manure management practices of the swine operation caused an "intolerable" odour and an "unreasonable" number of flies (Ibid.). The judge's decision was for the plaintiffs. They were awarded $500 dollars per day for each "smelly" day, and $100 dollars per day, for every other day (Ibid.). The ERS noted that legal implications of livestock operations are evolving quickly, and producers must adjust to these changing conditions. Though each lawsuit would undoubtedly be different, legal costs could be viewed as another cost to associate with manure management.

There may also be a financial impact on rural residents when intensive livestock operations are located in the vicinity of the residence. Palmquist et al. (1997) estimated that rural residential values in their US study area dropped by 9 percent when intensive pork operations were situated close to the rural residences. Serecon (1998) evaluated the social and economic impact of hog operations in Alberta. Their case-study and survey collected data on capital and operating costs for the farm businesses however a detailed cost analysis of the total cost of manure disposal were not reported. Serecon's study indicated that on average, odor from manure disposal was the most important concern of local residents with respect to hog operations. The concerned increased with closer proximity to the livestock facility however the overall average level of concern was not high.

Conclusions

Livestock operations in Alberta have important impacts on the economy of Alberta. Manure is a by-product of livestock production. The review of the science on manure examined the environmental impacts of manure. These include water pollution, air pollution, greenhouse gases, and soil degradation. There are several technologies for managing manure on-farm and off-farm. These include nutrient recycling through soil application and composting. Soil application of raw manure can lead to the environmental problems already reviewed as well as socio-economic impacts on society. Composting reduces the volume of manure, but increases the nitrogen loses from the manure. As well, it could possibly increase the manure's contribution to greenhouse gases.

This review, using a very simplistic approach, estimated that more than 6.3 million tonnes of manure were generated in Alberta in 1996. Other studies estimate far higher annual manure production. On a province-wide basis, there is adequate cropland area to make use of all the nutrients available in the manure it produced. Benefits of manure are constrained by both hauling costs to apply to soil, and the costs of managing the manure itself. The finding that manure management is generally a net-cost to the farm business provides economic incentives to over-apply manure on fields near the livestock manure storage site. This is similar to the conclusions presented by De Vos et al. This minimizes the costs to the business, but may create greater off farm costs for society or the environment. Environmental and social impacts are documented. However, the economic costs are not well documented. Any economic analysis should incorporate the dynamic nature of manure production, and the management of manure through recycling through soil.

The on-farm economic analysis of manure management used by researchers can be categorized into combinations of four general approaches.

- Opportunity Cost: Value the nutrient content of manure using commercial fertilizer values and consider the manure or manure product as a commercial fertilizer substitute or supplement. The additional soil benefits are more difficult to quantify.
- Crop Benefit: Value the direct crop benefit by comparing soil with manure applied versus a control with no manure applied. Yields and crop prices are included in the analysis and it attempts to indirectly price the additional soil benefits of manure application.
- Cost of Business: View the manure exclusively as a by-product of livestock production and evaluate methods for minimizing the cost of disposal.
- Business Enterprise: Manure production is a value-added business and uses a separate business enterprise approach such as commercial compost production.

The economic evaluation of manure handling reviewed here typically indicated that manure handling is a net cost to the farm business. No studies analyzing commercial composting were reviewed. Those studies suggesting that manure can be economically transported up to 300 km from the manure storage site used a crop benefit approach combined with a cost of business approach. Those studies ignored any possibility of substitution with commercial fertilizer, and attributed all crop benefits to the manure. Other studies would suggest that these benefits, or hauling distances up to 300 km, are overestimated when this is for application to soils for commercial crop production. The statement by a few of the studies reviewed here that manure is a valuable resource, and (by implication) a value-adding enterprise to the business, is only partly true. Manure has plant nutrient value. However, those studies that attempted a systems approach (or, at the very least, a more complete investment analysis) generally showed manure to be a net cost to the farm business. This precludes viewing manure management as a value-added enterprise. The nutrients in the manure only have on-farm value if they can be used in another enterprise (such as a cropping enterprise), in such a way that it reduces costs or adds to profits. Additional nutrients not required in the near-term by the soil and plants likely have little economic value to the cropping enterprise. Banking nutrients in the soil may not be an economically viable strategy. This reduces the incentives to view manure and its application to soils as a value-adding activity for the crop enterprise versus a cost minimization strategy employed by the livestock enterprise. Environmental regulations imposed on the business become the economic constraints that determine how the manure will be managed.

However, viewing the manure as strictly a cost minimization problem, focusing only on the minimum cost of disposal, does ignore this crop benefit or associated "environment" costs. For example, composting significantly reduces the volume of raw manure. At the same time, the value of additional nitrogen losses may actually be of greater cost than the reduced costs of handling the compost. Composting also releases greenhouse gases. No explicit scientific accounting was given of the tradeoff between decreased threat of water contamination versus the potentially increased release of greenhouse gases. The tradeoff of composting may in part be trading more localized negative impacts (water contamination) for more widespread negative impacts (greenhouse gases). This review is not a critique of the science and cannot evaluate whether this tradeoff just discussed has scientific merit. De Vos et al. would concur that the off-farm benefits and costs are not very accurate.

Several studies compared the costs of manure handling systems for different types of livestock operations. The investment analysis, while useful, did not always conform to the best analysis methodologies available. None of the studies, except Freeze (2000), attempting to use a systems approach, were based on Alberta conditions. At best, only one of the published studies explicitly incorporated the dynamic interactions of the livestock operation with a cropping enterprise, to analyze the on-farm management of manure. This may, in part, be related to the complexities of modeling the key components in the system, while including the dynamic time-related interactions between soil, manure, and the environment. Freeze (2000) is developing a systems model for beef feedlots in Alberta. Again, as discussed in De Vos et al., the off-farm costs and benefits, and the related science, need a lot more research. The investment and management analysis for Alberta was limited. It would be difficult to use the information reviewed here for either on-farm decision making, or for policy decision making for Alberta livestock operations.

Further Economic Research

The review of the science of manure management indicates some relatively simple areas for clarification. By the conclusion of this review, the authors were not sure just how much manure is produced in Alberta. There are widely varying estimates and no definitive definition for comparing quantities of manure produced by different types of livestock operations. The moisture content from manure generated by different livestock enterprises varies widely. The measure of Janzen et al. (1999), based on macronutrient content, may be the most useful for comparing between different types of manure. The science is still uncertain about the long-term impact of repeated manure applications to soils, nitrogen losses, and a host of other technical details that economists will require to better evaluate the manure management systems. Research is ongoing on the science of manure.

The economic analysis reported wide variations in the economic benefits or costs of manure management, associated with various manure management systems. Other sources, such as commercial suppliers for intensive livestock, may outline more explicit on-farm analysis. However, these were not found or reviewed here. Wide variations in approaches used for economic benefit analysis (from the farm perspective) were observed. Most economic analysis ignored the systematic nature of the manure management decision. A simpler cost minimization approach to on-farm analysis may be appropriate, but will miss the dynamic nature of the analysis. Grusenmeyer and Cramer (1997) recommend a multi-disciplinary systems approach to evaluating manure management for the farm business and for the policy maker. The off-farm costs and benefits to society were discussed but not valued. This is another fruitful area for economic research.

Little farm gate economic research applicable to Alberta on cost and benefits of manure systems for commercial farms for feedlots, dairy, pork or poultry was found. Much of the economic methodology could be improved. Overall, the conclusions from this review indicate several areas for future economic farm manure management. Several on-farm case studies could involve an analysis of "benchmark" farms. Information such as the costs and benefits mentioned in this paper could be analyzed for the benchmark farms. This would provide better information for on-farm decision making in a simple setting particularly as this relates to capital costs and operating costs.

A systems model for on-farm analysis could provide more complete analysis of the on-farm and policy implications of various decisions. Freeze (2000) has started work on a systems model for a beef feedlot. Different models for different livestock operations would be required. This analysis could be optimization models or simulation models that include:

- Livestock and manure interactions. The production decision has a direct impact on the quantity and quality of manure.
- Type of livestock operation. There might be separate models for different types of livestock operations.
- Soil, plant and manure interactions through time and space.
- Capital and investment analysis. Applications of real options analysis might contribute to the dynamic nature of this analysis.
- Environment constraints and or regulatory constraints.
- Plant yield, price and cost variability since the cost of commercial fertilizer and the value of the crop have a large impact on the economics of manure management.

Different scenarios could be evaluated to examine the impact of various policy proposals or to assist with making on farm management decisions. Non-market economic methodologies may also prove to be valuable tools in the analysis of manure management decisions at the farm level and their off farm socio-economic impact.

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Appendix A: Tables

Table 1: An Illustration of Manure Bulkiness

Type and Method of Fertilizer Application	**Amount of material (kg) required to give one kg of nutrient**		
	Nitrogen	Phosphate	Potash
Anhydrous Ammonia	1.2	---	---
Urea	2.5	---	---
Blended Fertilizer (20-20-20)[1]	5	5	5
Solid Chicken Manure Spring Applied - Not Immediately Incorporated	70	133	104
Liquid Swine Manure Spring Applied - Immediately	526	1430	714
Liquid Swine Manure Fall Applied	1250	1430	714

Ontario Ministry of Agriculture and Rural Affairs, OMAFRA. 1997
1. 20-20-20 represents 20% N, 20% P_20_5, and 20% K.

Table 2: Nutrient Value of Different Types of Manure

Manure	**Nitrogen**	**Phosphate**	**Potash**	**Total Value(Can$)**
Dairy Liquid	1.40kg/1000litres	0.70kg/1000litres	2.99kg/1000litres	$2.55/1000litres
Swine Liquid	2.39kg/1000litres	1.10kg/1000litres	1.99kg/1000litres	$3.02/1000litres
Poultry Liquid	5.08kg/1000litres	2.49kg/1000litres	3.39kg/1000litres	$6.44/1000litres
Dairy Solid	1.49kg/tonne	1.49kg/tonne	5.48kg/tonne	$4.20/tonne
Poultry Solid	8.97kg/tonne	8.97kg/tonne	12.46kg/tonne	$17.53/tonne

AAFRD, 2000 based on data from Hilborn, 1992.

Table 3: Quantities of NPK Per Tonne of Beef Cattle Manure

Type of Livestock	**Moisture (%)**	**Total N %**	**N**	**P_2O_5**	**K_2O**
			kg/tonne	**kg/tonne**	**kg/tonne**
Beef open	50	0.85	2.6	5.6	8.2
Beef paved	65	0.65	2.3	2.0	4.6
Beef closed	92	0.45	1.7	2.0	5.1

AAFRD, 1996.

Table 4: Total Animal Units and Manure Produced in Alberta (1996).

Livestock Type	Conversion Factor	Animal Units	Manure Equivalent (in tonnes)
Laying Hens	125	15178	31874
Chicken Broilers	1000	7589	15937
Bulls	1.5	177900	373590
Dairy Cows	0.75	77123	161958
Beef Cows	1	2016889	4235467
Beef Feeders	4	461315	968762
Finishing Hogs	15	102943	216180
Sows/Boars	4	46417	97476
Horses/Ponies	1	149960	314916
Total		3055314	6416160

Assumptions for tables 7 and 4 and using numbers from Tables 5 and 6.

1. According to AAFRD poultry in Alberta is split; 20% layers and 80% broilers.
2. Beef feeders are on feed for 12months after weaning.
3. Heifers of 1year or more are the equivalent of steers (beef feeders)
4. Calves less than 1year were ignored.
5. Horses and ponies were grouped together.
6. The number of finishing hogs was found by subtracting sows and boars from the total of pigs.
7. Boars and sows were grouped together.
8. Turkeys were ignored.
9. One bull is equivalent to 1.5 animal unit.
10. Chaw and Abiola (1999, p. 302) report an estimate of 46.8 million tonnes of manure were produced in Alberta in 1992. 42.3 million of these tonnes were from the cattle industry.

AAFRD, 2000.

Table 5: Livestock Populations in three Alberta Counties (1996)

Livestock Type	Lethbridge	Ponoka	Grand-Prairie	Alberta
Total cattle & calves	402048	185752	85237	5942257
Total hens and chickens	929823	81538	139855	9485635
Total turkeys	17066	1547`	301	842798
Bulls 1 year & more	1614	3345	2013	118600
Dairy cows	8906	7152	518	102830
Beef cows	18255	60887	33325	2016889
Heifers 1 year & more	191688	31158	10447	952563
Steers 1 year & more	138887	25991	9812	892696
Calves less than 1 year	42698	57219	29122	1858679
Total pigs	114647	71498	12282	1729810
Boars, 6 months & more	709	391	78	11471
Sows & bred gilts	12350	7155	1094	174195
Horses & ponies	2089	3820	3391	149960

AAFRD - Census of Agriculture 1996. Lethbridge is located in Southern Alberta, Ponoka is located in Central Alberta and Grand Prairie is located in Northern Alberta.

Table 6: Livestock Conversion into Animal Units

Type of Livestock	**Number of Animals to give one *Animal Unit***
Dairy (including replacements)	0.75 milking cows
Beef Cow (includes calf)	1 cow
Beef Feeders	4 marketed feeders
Sows (includes litters)	4 sows
Finishing Hogs	15 marketed hogs
Sheep (includes lambs)	4 ewes
Horses	1 horse
Laying Hens	125 hens
Chicken Broilers	1000 marketed broilers

Hilborn, 1992.

Table 7: Total Animal Units and Manure Produced in Lethbridge County (1996).

Livestock Type	Conversion Factor	Animal Units	Manure Equivalent (in tonnes)
Laying Hens	125	1488	3125
Chicken Broilers	1000	744	1562
Bulls	1.5	2421	5084
Dairy Cows	0.75	6680	14028
Beef Cows	1	18255	38336
Beef Feeders	4	82644	173552
Finishing Hogs	15	6773	14223
Sows/Boars	4	3265	6857
Horses/Ponies	1	2089	4387
Total		124359	261154

Source: AAFRD, 2000 and based on numbers from Table 6 and assumptions given in Table 4 Note that this simple estimate which does not account for animal turnover in beef feedlots or pork operations is much lower that manure production estimates discussed in Chaw and Abiola (1999). Their references estimate that manure production in the County of Lethbridge was 1,058,000 tonnes in 1992 with 685,000 tonnes from beef feedlot and poultry manure and 373,000 tonnes from liquid dairy and hog operations.

Table 8: Timely Amounts of Manure Generated by One *Animal Unit*

Beef	Daily			Monthly			Yearly		
	lb	kg	Cu. ft	lb	Kg	cu. ft	tons	tonnes	Cu. Ft
Open lot	13	5.9	0.32	392	178	9.6	2.4	2.1	117
Paved	20	9.0	0.43	594	270	12.8	3.6	3.2	156

AAFRD, 1996. Beef Manure Management.

Table 9: Assumed Crop Nutrient Needs for Determining Land Base Guidelines

Nutrient	Dark Brown & Brown		Grey Wooded		Black		Irrigated	
	lbs/acre	kg/hectare	lbs/acre	kg/hectare	lbs/acre	kg/hectare	lbs/acre	Kg/hectare
Nitrogen	50	56	60	67	80	90	100	112
Phosphate	20	22	30	34	40	45	45	50
Potash	10	11.2	15	17	15	17	15	17

AAFRD, 2000-a, Appendix E

Table 10: Land Base (acres) for Feeder Piggeries

No. of Feeders	Soil Type							
	Dark Brown & Brown		Grey Wooded		Black		Irrigated	
	Intermittent	Annual	Intermittent	Annual	Intermittent	Annual	Intermittent	Annual
100	17	19	14	16	11	12	8	10
500	84	97	70	81	53	61	42	49
1000	169	194	141	162	106	121	84	97
2000	338	388	281	324	211	243	169	194
5000	844	971	703	809	528	607	422	485
10000	1688	1942	1407	1618	1055	1213	844	971

AAFRD, 2000-a, Appendix E

Table 11: Land Base (acres) for Beef Feedlots (finishers)

No. of Cattle	Soil Type							
	Dark Brown & Brown		Grey Wooded		Black		Irrigated	
	Intermittent	Annual	Intermittent	Annual	Intermittent	Annual	Intermittent	Annual
100	24	28	20	23	15	17	12	14
500	121	139	101	116	75	87	60	69
1000	241	278	201	231	151	174	121	139
5000	1207	1388	1006	1157	755	868	604	694
10000	2415	2777	2012	2314	1509	1736	1207	1388
20000	4829	5554	4025	4628	3018	3471	2415	2777
30000	7244	8331	6037	6942	4528	5207	3622	4165
40000	9659	11108	8049	9257	6037	6942	4829	5554
50000	12074	13885	10061	11571	7546	8678	6037	6942

AAFRD, 2000-a, Appendix E

Table 12: Application Rates for Hog Manure (at 96% moisture)

Total N %	N Supplied by Manure for Crop Production (lbs/acre)							
	Application in gallons/acre							
	30	40	50	60	70	80	90	100
0.20	3500	4700	5900	7100	8200	9400	10600	11800
0.25	2800	3800	4700	5700	6600	7500	8500	9400
0.30	2400	3100	3900	4700	5500	6300	7100	7800
0.35	2000	2700	3400	4000	4700	5400	6100	6700
0.40	1800	2400	2900	3500	4100	4700	5300	5900
0.45	1600	2100	2600	3100	3700	4200	4700	5200
0.50	1400	1900	2400	2800	3300	3800	4200	4700

AAFRD, 2000-a, Appendix F

Table 13: Application Rates for Beef Feedlot Manure (at 92% moisture)

Total N %	N Supplied by Manure for Crop Production (lbs/acre)							
	Application in tons/acre							
	30	40	50	60	70	80	90	100
0.50	10.1	13	17	20	24	27	30	34
0.55	9.2	12	15	18	21	24	27	31
0.60	8.4	11	14	17	20	22	25	28
0.65	7.7	10.3	13	15	18	21	23	26
0.70	7.2	9.6	12	14	17	19	22	24
0.75	6.7	9	11	13	16	18	20	22
0.80	6.3	8.4	10.5	13	15	17	19	21
0.85	5.9	7.9	9.9	12	14	16	18	20
0.90	5.6	7.5	9.3	11	13	15	17	19

AAFRD, 2000-a, Appendix F

Table 14: Trends of Canadian Livestock Value - Cash Receipt ($ ‘000,000)

Year	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Cattle	3627.1	3491.6	4003.4	4395.5	4261.3	4154.3	4366.0	4766.2	5147.6	5543.0
Hog	2021.2	1841.6	1787.1	2042.4	2031.8	2252.5	2884.1	2989.4	2230.2	2397.9
Diary	3154.8	3162.7	3089.5	3129.9	3354.5	3463.1	3514.7	3707.3	3844.8	3923.2
Poultry	1683.9	1654.8	1660.3	1751.3	1841.4	1878.5	2162.2	2073.7	2103.9	2087.5

Poultry is made up of chicken, hens, hatcheries and eggs.
Agricultural Economic Statistics, Catalogue 21-603, Statistics Canada.

Table 15: Trends of Alberta Livestock Value - Cash Receipt ($ ‘000,000)

Year	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Cattle	1564.7	1529.9	1809	2105.3	2185.6	2216.6	2344.4	2532.4	2743.8	3063.2
Hog	298.9	276.1	276.9	322.9	315.3	381.8	444.6	438.4	315.4	338.7
Diary	251.2	250.1	248.5	244.7	257.8	265.6	290.8	316.8	3611.5	327.1
Poultry	146.0	143.3	143.6	151.2	163.1	165.2	180.0	167.4	173.4	172.5

Poultry is made up of chicken, hens, hatcheries and eggs.
Agricultural Economic Statistics, Catalogue 21-603, Statistics Canada.

Table 16: Annual Alberta Values of Nutrients in Manure ('000 of Dollars)

Types of Livestock	Available N	P_2O_5	K_2O
Layers	202.6	601.1	109.7
Broilers	128.5	196.0	59.0
Beef	7850.2	14636.2	12320.8
Diary	220.9	265.6	305.6
Swine	311.1	668.7	232.1
Horses/Ponies	605.1	800.5	710.8
Total	9318.4	17168.1	13738

1. Average values (kg/tonne) from AAFRD http://www.agric.gov.ab.ca/agdex/400/400_27-2a.html, Appendix A.
2. Grouped bulls, beef feeders, and beef cows into Beef.
3. Grouped boars, sows, and finishing hogs into Swine.
4. Bolton (1999) cites unnamed references that valued manure produced in the prairie region of Canada at $164,000,000 and $159,000,000 for nitrogen and phosphorus respectively based on commercial fertilizer values in 1998.

Table 17: Cost Comparisons of Manure Systems

Systems	Investment (in US. Dollars)
Earthen Basin	$ 10,000 - 50,000
Waste Storage Structure Concrete/below ground	$ 60,000 - 75,000
Pre-stressed Concrete above ground storage	$ 60,000 - 75,000
Solid Manure Stacking Slab & Run-off Pond	$ 40,000 - 55,000
Slurry Storage/Steel tank	$100,000 -150,000
Used Slurry	$ 70,000 - 80,000

MacNeil and Sawyer, 1999.

Table 18: Liquid Manure Handling Costs

Site	Rate	Own	Custom
	L/ha	$/ha	$/ha
Dixon	38138	94.69	79.75
Burr	69391	147.44	145.10
Dixon	76287	159.91	159.52
Burr	80055	167.63	167.40
Burr	134083	242.02	280.38
Dixon	152564	275.37	319.02
Burr	268156	484.01	560.73

Fixed Quantity of 19,749,000litres/year
(Nagy et al. 1999)

Table 19: Solid Manure Handling Costs

Site	Rate	Own	Custom
	Tonnes/ha	$/ha	$/ha
Dixon	9.70	82.29	29.01
Burr	18.30	74.75	73.97
Dixon	19.50	75.32	46.09
Burr	36.60	71.12	76.01
Dixon	39.10	71.79	80.27
Burr	73.20	88.10	140.11

Fixed Quantity of 9,490tonnes/year
(Nagy et al. 1999)

Table 20: Net Manure Cost per Mature Dairy Animal in Michigan Systems Dairy Model With Two Different Herd Sizes (US $)

	Semi-Solid with daily haul to field	Slurry with 6 month storage facility - spread	Slurry with 6 month storage facility - injected
Dairy Size			
60 milk cows $/cow	157	222	241
60 milk cows $/Kilolitre of milk produced	16	22	24
250 milk cows $/cow[1]	70	117	131
250 milk cows, $/Kilolitre of milk produced	7	12	13

Source: Borton et al. (1995). Data used applies to Michigan region of United States.
1. Custom application was calculated to cost $104/cow or $10/KL of milk

Table 21: Comparison of Farm Gate Manure Costs in Ontario for Three Commercial Farms

Farm Type	Capital Invested in Manure Handling $	Annual Ownership (Annualize NPV) $	Annual Operating Costs $	Annual Economic Benefits $	Annual Net Benefits (Costs) of Manure $	Net Cost per tonne of manure/ year $
Poultry: Solid[1]	128,700	31,067	4,718	16,027	(19,758)	(43.13)
Swine: Liquid[2]	181,308	42,778	8,966	25,369	(26,374)	(4.23)
Dairy: Liquid[3]	50,382.50	12,060.00	3072.07	15,464.60	332.70	0.06

Source: Stonehouse (1997).

1. Poultry: 26,000 broiler/roaster on deep wood shavings in two story barn handled in solid form in two story barn with front end loaders and box spreaders. Total manure 458.1 tonnes/year (moisture content not provided).

2, Swine: Liquid manure for 550 sow farrow-to-finish with slatted floors, open concrete storage tank and irrigation/tank spreader. Total manure production 6,239.5 tonnes/year (moisture content not provided)

3. Dairy: 70 cow dairy using liquid alley-flush system, three earthen lagoon storage system and reel-in irrigation for field operations. Total manure 6035/tonnes/year (moisture content not provided). Upgrades to the manure handling system completed after this analysis would change the net benefit/tonne/ year to a negative number.

Table 22: Comparative Costs of Composting Methods

Composting Method	**Estimating Cost per Ton of Incoming Material (US$)**
Windrow composting using a loader for turning	$ 5-$10
Windrow composting using specialized windrow turners	$15-$30
Aerated static pile systems	$20-$50
In-vessel systems	$50-$100

MacNeil and Sawyer, 1999.

Table 23: Costs for Composting, Assuming a $12 per hour Labour Rate

	Straw-Based Compost		Wood-Based Compost	
	Total (65 tonnes)	Cost per Tonne	Total (85 tonnes)	Cost per Tonne
Hauling to Compost Site	$51.00	$0.79	$58.00	$0.68
Windrow Maintenance	$218.00	$3.36	$224.00	$2.63
Turning Windrows	$181.00	$2.77	$199.00	$2.34
Loading from windrows	$94.00	$1.45	$123.00	$1.45
Total Costs	$544.00	$8.37	$604.00	$7.11

The initial weight of manure was 183tonnes for straw based and 207tonnes for wood-based compost. Compost weight of 65tonnes and 85tonnes were from the initial weight of manure of straw-based and wood based respectively after composting.

(Freeze et al. 1999)

Table 24: Costs for Composting, Assuming an $8 per hour Labour Rate

	Straw-Based Compost		Wood-Based Compost	
	Total (65 tonnes)	Cost per Tonne	Total (85 tonnes)	Cost per Tonne
Hauling to Compost Site	$45.00	$0.70	$51.00	$0.60
Windrow Maintenance	$191.00	$2.93	$196.00	$2.30
Turning Windrows	$163.00	$2.51	$181.00	$2.12
Loading from windrows	$87.00	$1.34	$114.00	$1.34
Total Costs	$486.00	$7.48	$542.00	$6.36

The initial weight of manure was 183tonnes for straw based and 207tonnes for wood-based compost. Compost weight of 65tonnes and 85tonnes were from the initial weight of manure of straw-based and wood based respectively after composting.

(Freeze et al. 1999)

Table 25: Hauling Costs of Manure and Compost ($12/hr Labour Rate)

		Compost		Manure		Difference	
		Total Cost	$ per tonne	Total Cost	$ per tonne	Total Cost	$ per tonne
Straw-based	5km	$44.00	$0.67	$256.00	$1.40	$213.00	$3.27
	12.63km	$110.00	$1.69	$647.00	$3.53	$537.00	$8.27
	40km	$348.00	$5.35	$2,048.00	$11.19	$1,700.00	$26.16
Wood-based	5km	$57.00	$0.67	$290.00	$1.40	$233.00	$2.74
	12.86km	$146.00	$1.72	$745.00	$3.60	$599.00	$7.04
	40km	$455.00	$5.35	$2,317.00	$11.19	$1,862.00	$21.90

(Freeze et al. 1999)

Table 26: Hauling Costs of Manure and Compost ($8/hr Labour Rate)

		Compost		Manure		Difference	
		Total Cost	$ per tonne	Total Cost	$ per tonne	Total Cost	$ per tonne
Straw based	5km	$39.00	$0.59	$227.00	$1.24	$188.00	$2.90
	12.74km	$98.00	$1.51	$578.00	$3.16	$480.00	$7.38
	40km	$308.00	$4.75	$1,815.00	$9.92	$1,507.00	$23.18
Wood based	5km	$50.00	$0.59	$257.00	$1.24	$206.00	$2.43
	12.99km	$131.00	$1.54	$667.00	$3.22	$536.00	$6.30
	40km	$403.00	$4.75	$2,053.00	$9.92	$1,650.00	$19.41

The total cost values in Tables 25 and 26 for compost and manure represent only the actual hauling cost based on the labour rate for each table. In arriving at the breakeven distance of 13km, other costs like pen cleaning and loading were added.

(Freeze et al. 1999)

Table 27: Initial and Final Weights of Compost Windrows

Windrow Type	Initial tonnes	After Curing tonnes
Straw based Compost	183	65
Woodchip based Compost	207	85

(Freeze et al. 1999)

Table 28: Characteristics of Manure Before and After Composting

	Fresh Manure End of May	After Active Composting End of August	After Curing End of Nov
% Dry Matter	30	55.50	66.40
Moisture % wet weight	70	44.50	33.60
pH	7.10	7.90	7.50
Electrical Conductivity (Ds/m)	7.50	7.50	7.70
Bulk Density kg of dry matter / m3	99	339	458
Total Carbon % of dry matter	34.20	15.30	14
Total Nitrogen % of dry matter	1.80	1.50	1.50
Total Phosphorus % of dry matter	0.25	0.30	0.33
C/N ratio	19.30	10.70	10.30

(Freeze et al. 1999)

Table 29: Intensive Livestock Operation – Minimum Size (Based on 300 AU)

Livestock Type	Threshold Number
Milking Cows, IAL (AG)	150
Beef Cows, IAL (AG)	240
Sow, Farrow to Finish (AG)	240
Broiler Chicken (IA)	60000
Bison, Cows or Bulls (IA)	300

IAL – Including Associated Livestock
AG – Animal Groups
IA – Individual Animals.
AAFRD, 2000-d.

Table 30: Notification Distance Based on Animal Units

Animal Units	Radius (miles)
300 - 500	0.5
501 - 1 000	1.0
1001 - 5000	1.5
5000 - 10000	2.0
10000 - 20000	3.0
> 20000	4.0

AAFRD, 2000-d.

Appendix B: Figures

Figure 1: Storage of Solid Manure by Ecozone

Results of the 1995 Farm Inputs Management Survey: Boreal Plains and Prairies represents eco-zones found in prairie provinces in Canada.

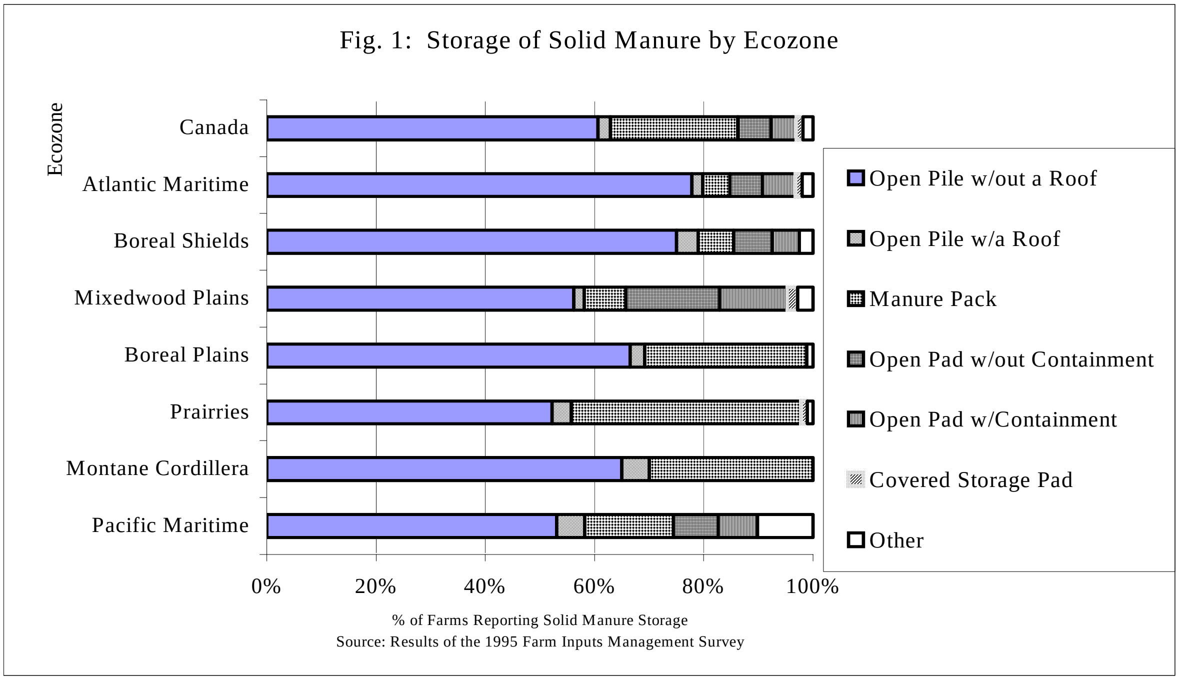


Figure 2: Beef Cattle Manure Application

Occasional Paper No. 2 Water Resource Institute. University of Lethbridge

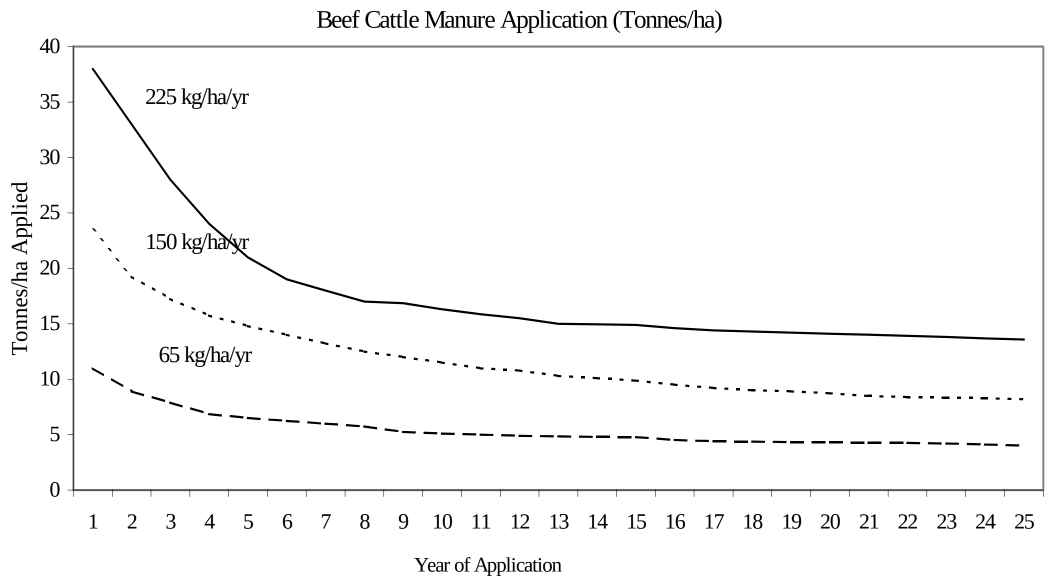
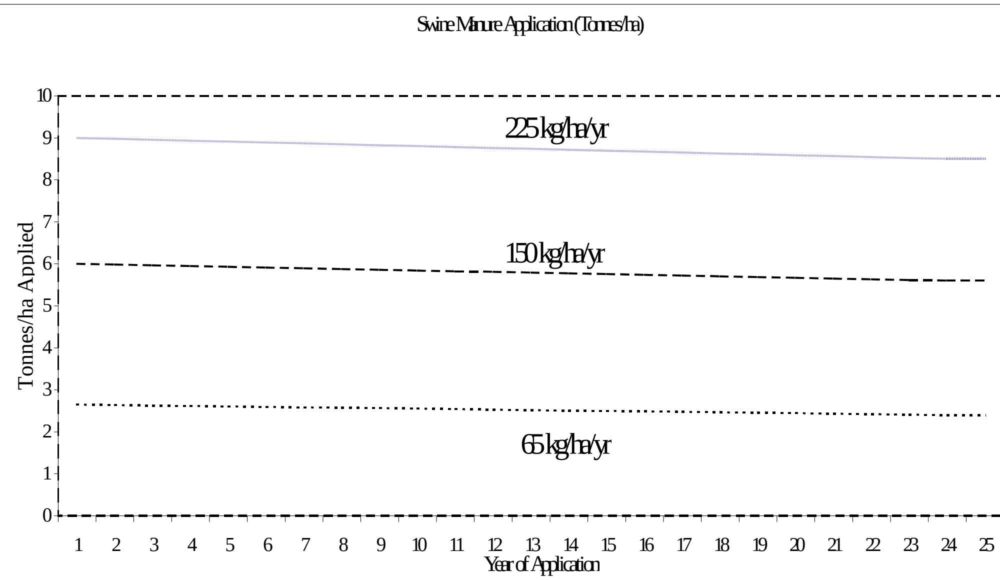


Fig. 2 Beef Cattle Manure Application for 3 Mineralization Rates
Source: Occasional Paper No. 2 Water Res. Institute. The University of Lethbridge

Figure 3: Swine Manure Application for 3 Mineralization Rates



Swine Manure Application for 3 Mineralization Rates
Source: Occasional Paper No. 2 Water Res. Institute. The University of Lethbridge

Appendix C

Lethbridge Dark Brown Chernozemic Clay Loam Soil

This experiment involved repeated application of manure to both irrigated and non-irrigated sites to determine the long-term nitrogen balance. A nitrogen balance was constructed for a site at Lethbridge, in which various rates of 1- to 2-year-old manure (up to 180 tonnes/ha/year) was applied annually. Manure was applied at 0, 30, 60 and 90 tonnes/ha (wet weight) on the non-irrigated land and at 0, 60, 120 and 180 tonnes/ha on the irrigated land. Cumulative nitrogen uptake by crops was significantly enhanced by manure application under both moisture regimes, though higher rates of manure did not increase uptake beyond that observed at 30 tonnes/ha (non-irrigated) or 60 tonnes/ha (irrigated) (Chang and Janzen, 1996).

Under non-irrigated conditions, the entire nitrogen (N) applied in manure was accounted for by crop removal, total soil N and soil NO_3-N, suggesting that losses through leaching, denitrification, and ammonia volatilization were negligible (Chang and Janzen, 1996). However, under irrigation (particularly at higher rates of manure application), appreciable amounts of nitrogen were lost by leaching and volatilization. The proportion of N mineralized was independent of application rate and irrigation regime (Chang and Janzen, 1996). Approximately 56% of the N applied in the 1- to 2-year-old manure was made available to plants for the entire experimental period of almost 20 years.

Lethbridge Clay Loam Soil (Dark Brown) Chernozemic.

This experiment evaluated the effects of long-term annual manure application on barley performance. Feedlot cattle manure was applied annually from 1973 to 1989 to irrigated plots at 0, 60, 120 and 180 tonnes/ha on wet weight basis and 0, 30, 60 and 90 tonnes/ha to non-irrigation plots. Under non-irrigated conditions, grain yields of barley generally decreased with increasing rates of manure application, but protein concentration increased with higher rates of manure application. Grain yields at the 30tonnes/ha manure rate generally exceeded those at the 60 and 90 tonnes/ha rates (Chang, Sommerfeldt and Entz, 1993). Soil salinity, mostly in the surface soil, increased with increasing rates of manure (Chang et al, 1990 and 1991), but there was sufficient leaching that the salinity build-up did not limit barley growth (Chang, Sommerfeldt and Entz, 1993). Barley yields under irrigation were not reduced even at a manure application rate of up to three times the recommended rate of 60 tonnes/ha.

Dark Brown Chernozemic Soil (Lethbridge Loam)

The effects of 20 annual applications of feedlot manure on labile soil phosphorus were studied. The manure application rates were 0, 30, 60 and 90 tonnes/ha (wet weight) and 0, 60, 120 and 180 tonnes/ha for non-irrigated and irrigated blocks respectively. After 10 years of feedlot manure loading, soil phosphorus (P) and phosphate levels increased with increasing rates of manure (Dormaar and Sommerfeldt, 1986). However, these increases diminished at triple the recommended loading regimes (Dormaar and Chang, 1995).

Increased phosphorus levels in the soil have been reported to interfere with uptake of zinc and copper (Janzen et al. 1993; Eghball and Power, 1994). Conversely, Chang et al. (1994) showed that high rates of phosphorus applied through manure did not suppress uptake of zinc and copper by barley. The high availability of micro-nutrients in manured soil (Chang et al, 1991) may prevent the suppression of uptake of micro-nutrients, which was observed when comparable amounts of inorganic phosphorus fertilizer were applied to similar soil (Janzen et al, 1993). Repeated annual applications of feedlot manure to southern Alberta soils, even at the recommended rates of 30 tonnes and 60 tonnes/ha (wet weight) for non-irrigated and irrigated lands, respectively, have long-lasting residual effects (Dormaar and Chang, 1995). Such effects will be beneficial for heavily eroded land that has developed calcareous surface horizons.

Desurfaced Fine Loamy, Mixed Typic Haploboroll (Lethbridge Series)

An experiment on this soil type involved application of various forms of cattle manure (fresh, old, composted, or mixed with wood shavings), hog manure, and poultry manure in the restoration of productivity to a site where the Ap horizon (15-cm depth) has been mechanically removed to simulate erosion. The manure and crop materials were incorporated into the degraded surface on an equivalent dry-weight basis at 20 tonnes/ha. Cattle manure containing wood shavings was not as effective in restoring soil productivity as the other types of cattle manure (Larney and Janzen, 1996). This was probably due to its lower nitrogen content and higher carbon to nitrogen (C/N) ratio.

Based on plant dry matter production, the hog manure and poultry manure amendments resulted in significantly higher crop yields than the eroded check treatment in the entire 3 year period of the study (Larney and Janzen, 1996). However, the longevity of this effect is unknown. Composted cattle manure, which has reduced moisture content and odour, was almost as effective in restoring productivity as fresh or old cattle manure (Larney and Janzen, 1996).

Calcareous Dark Brown Chernozemic Soil

The soil in this experiment was developed on loam-textured lacustrine material. A wheat-fallow experiment (from 1980 to 1985) was used to determine the effects of 30 tonnes/ha or 150 kg commercial fertilizer N (as urea) + 150 kg commercial fertilizer P (as superphosphate)/ha on restoring soil productivity. In 1981 (1st year.), the fertilizer and manure treatments resulted in wheat yields that were greater than the yields from the check treatments for each of the respective soil treatments (Dormaar, Lindwall and Kazub, 1988). In 1982 (2nd year.) however, there were no differences between the fertilizer treatments in the undisturbed soil, but plots with manure applied had greater phosphorus availability in the eroded plots and higher NO_3-N levels than the fertilizer or check plots. In 1983 (3rd year), a very dry season, only the manure application on the eroded soil treatments resulted in yields greater than those on check or fertilized plots for those soil treatments (Dormaar, Lindwall and Kazub, 1988).

Plots receiving manure had more organic matter in 1982 and in 1984 (2nd and 4th year), while manure and fertilizer applied plots had a similar but significantly higher NO_3-N levels than the check plots in the 4th year (Dormaar, Lindwall and Kazub, 1988).

The change in total N and organic matter content between 1980 and 1984 (up to the 4th year) did not differ significantly for the erosion treatments but the change for plots receiving manure treatment was greater than for unfertilized plots or plots receiving commercial fertilizer (Dormaar, Lindwall and Kazub, 1988). Available phosphorus also had a greater increase within the same period as compared to check and fertilizer plots.

Manure aided increased crop production, even on severely eroded land, contributing much need organic matter, total nitrogen, NO_3-N, and available phosphorus to the soil (Dormaar, Lindwall and Kazub, 1988). However, through slow release, only small amounts were available at any one time so that the actual nitrogen and phosphorus applied with the manure did not damage the crops in drought stress years.

Manure was effective in restoring soil organic nitrogen and phosphorus, especially under non-irrigation. It had a positive effect on protein concentration of barley and wheat yields, but at a rate higher than the recommended application rate. This is likely to have adverse environmental effects. Both manure and commercial fertilizer were effective in restoring productivity to eroded soil. However, to determine the application of manure and/or commercial fertilizer, the residual effect and the cost of hauling the manure must be evaluated.

Appendix D: Proposed Livestock Regulations for Alberta

The following is a brief review of the proposed regulation on intensive livestock operation and nutrient management. Intensive livestock means an operation where the number of animals in confinement on a farm equals or exceeds the threshold of 300 animal units. It is an operation where the livestock are confined in facility(ies) at a density of 43 animal units per acre for greater than 90 consecutive days, and the producer has to manage the manure generated at the facility(ies) (AAFRD, 2000). Table 29 in Appendix A shows the animal unit calculations.

New and expanding livestock operations will require approval from Alberta Agriculture, Food and Rural Development (AAFRD) prior to construction. These are operations that are located in a 1-in-100 year flood plain, or within 100metres of a open body of water, irrigation works, spring, or over a groundwater source which has less than 4metres of soil between the manure storage facility and the water bearing formation. The producer will need to supply AAFRD with information on crops that will be grown (nutrient requirements and amount of manure and supplemental fertilizer that will be applied) and the soil conditions (classifications and description). Depending on the number of animal units (Table 30 in Appendix A), persons who reside on, or own land falling within a certain prescribed radius of the intensive livestock operation, must be notified.

Livestock operations located within 100metres of a river, stream or canal must notify municipalities and persons who are located 10 miles downstream of the livestock operation if the water is used for human consumption or commercial processing of food. The distance decreases to 3 miles, if the water is used for other purposes. Restrictions on applying manure on snow or frozen ground may be imposed depending upon the slope, location of open bodies of water on or adjacent to the land, size of riparian area adjacent to or surrounding the bodies of water and the soil type. The operators of intensive livestock operations may be mandated to keep records of date of application, volume applied, size of field and soil test results prior to application. Restriction on the location of feeding and bedding sites close to open bodies of water are proposed.

The proposed regulation specifies the way manure shall be applied to the different soil types in Alberta. Before any application is carried out, soil sample analysis must be to determine the contents of mineral nitrogen and phosphorus, electrical conductivity, and sodium conductivity in the soil. This is to avoid overloading the macronutrients of nitrogen or increasing the soil "salt" levels to too high a level. The proposals provide the following guidelines. Manure application must not occur when the top 60cm of soil profile, based on fall soil sampling, contains:

(a) more than 45 lbs/acre NO_3 nitrogen in coarse textured soils (more than 45 % sand) underlain by a groundwater source with less than 4metres of covering soil or

(b) more than 90 lbs/acre NO_3 nitrogen in coarse textured soils (more than 45 % sand) in Black, Luvisolic, Brown or Dark Brown soils, or

(c) more than 180 lbs/acre NO_3 nitrogen in medium to fine textured soils (less than 45 % sand) and in Black or Luvisolic soils.

Application may be prohibited when the top 15 cm of the soil profile has a Sodium Absorption Ratio greater than 8.0 (saturated paste extract), or Electrical Conductivity (EC) greater than 4.0 ds/m. This is to prevent high "salt" build ups in the soil. To prevent excessive nitrogen (and surface and ground water contamination), manure application at more than 210 lbs/acre of mineral nitrogen or 810 lbs/acre of total nitrogen may be restricted depending upon the approved management plan. Note that the proposed application rate for manure is based upon the quantity of nutrients in the manure. Restrictions on surface application and time to incorporation may also apply.

Appendix E: Alternative Investment Analysis Methods to NPV

The first of these alternative rules to Net Present Value (NPV) is the *Payback Period Rule*. An investor chooses a cutoff period (e.g., 2 years). He or she looks at the cash flows that will be received over the next few years. When the amount to be received exceeds the initial investment, then the investment is recovered. In the case of a two-year cutoff period, an investment project that has a payback period of two years or less will be accepted. Those that do not pay off in this time are rejected (Ross et al, 1999).

There are some problems with the payback period method. The timing of the cash flows is not considered. That is, they are not discounted properly (as they would be in NPV analysis) (Ross et al, 1999). A second problem is that the method does not include payments that occur after the payback period. A project that has a positive cash flow after the payback period would definitely be preferred to one that does not. There is also a problem with the choice of a payback period. Using the Payback Period Rule, the choice is arbitrary (Ross et al, 1999). A method such as NPV has a standard for choosing important aspects of financing, such as discount rates.

Another rule noted by Ross et al. (1999) is the *Average Accounting Return* (AAR). This method is defined as "the average project earnings after taxes and depreciation, divided by the average book value of the investment during its life" (Ross et al, 1999). The authors noted that this method is used frequently in business. In order to calculate the AAR, an investor must first determine a project's average net income. This is done by summing the projected net income for each year in the life of the project, then dividing by the life span (Ross et al, 1999). Next, the average investment must be determined. A project is expected to depreciate at a set amount per year (called straight-line depreciation). That is, each year, a project will be worth less by a specific amount (e.g., a building worth $500,000 in the first year may be worth $400,000 in the second, and so on). The expected values of an investment over the life span are summed, then divided by the life span, to get average investment (Ross et al, 1999). The AAR can then be calculated by dividing the average net income by the average investment. The resulting percentage is the AAR (Ross et al, 1999).

One major flaw of the AAR method is the fact that accounting values (net income, book value of investment) are used to judge the value of the investment. A better analysis of the investment could be performed using the cash flows associated with a project (as in NPV) (Ross et al, 1999). Also, as in the case of the Payback Period Rule, the AAR method does not take timing of cash flows into consideration. The AAR method also requires an arbitrary cutoff date to be chosen (Ross et al, 1999).

The *Internal Rate of Return* (IRR) method is used to find a single number that explains the benefits of a project (Ross et al, 1999). The number is an *internal* rate of return because it does not depend on the prevailing interest rate in the capital market. According to Ross et al. (1999), this method is the most important alternative to the NPV approach. If NPV is written as:

$$NPV = Initial\ Investment + \frac{First\ Period\ Cash\ Flow}{1+r}$$

where r is the discount rate, the IRR is the rate r at which NPV will equal zero. That is, a company (or farmer) would be equally willing to accept or reject a project at this discount rate. The company or farmer will accept the project if the discount rate is above the IRR, and vice-versa. This is the standard IRR rule.

Problems associated with IRR are not as apparent as those with other methods. Consider two types of project. If a company pays money first, and receives money later, this is an investing-type project. If a company receives money first, and pays money later (e.g., conference attendees paying fees in advance), this is a financing type project (Ross et al, 1999). A financing-type project can reverse the standard IRR rule (see above). This can be a problem, unless it is fully understood (Ross et al, 1999). A project's cash flows may also exhibit two changes of sign (e.g., -$100, $200, -$150). A project such as this may exhibit more than one IRR, due to the "flip-flops" in sign (Ross et al, 1999).